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NOTE.—The papers included in the annual volume "Shorter contributions to general geology" are issued separately, with the final pagination, as soon as they are ready. The last paper will include a volume title-page, table of contents, and index for the use of those who may wish to bind the separate parts. A small edition of the bound volume will also be issued, but copies can not be supplied to those who have received all the parts.

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SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY, 1916.

EVAPORATION OF BRINE FROM SEARLES LAKE, CALIFORNIA.

By W. B. Hicks.

INTRODUCTION.

The bed of crystalline salts known as Searles Lake,[1] in southeastern California, contains the most valuable potash-bearing brine known in the United States. This salt body has an exposed surface area estimated at 11 or 12 square miles and an average depth of about 70 feet. For the most part it is firm and compact enough to support a wagon and team, even during unusually wet seasons, when it is sometimes flooded with a thin sheet of water that dissolves the surface salts to a slight extent. The deposit contains in the interstices between the salt crystals a saturated brine the volume of which is estimated to be more than 25 per cent of that of the entire saline mass.[2]

The brine contained in this so-called lake carries about 2.1 per cent of potassium, or the equivalent of about 4 per cent of potassium chloride. It is composed chiefly of the chlorides, sulphates, carbonates, and borates of sodium and potassium. It is essentially different from the brines used in the manufacture of potash in Germany, and on that account a different process is required for the extraction of the potassium from it. Economical methods for extracting the commercial salts, including potash, from this brine are now eagerly sought, but none yet tried have been proved commercially successful. Fractional evaporation and crystallization form an essential part of the methods which appear to give the most promise, and detailed knowledge of the effect of evaporation on these brines is therefore of special interest. It is difficult to predict from theoretical considerations what will be the effect of evaporation on the various constituents of so complicated a system as that represented by the brine of Searles Lake. All the necessary data for an adequate discussion of the subject have not been worked out, and direct experimental data on the evaporation of brines of similar composition are meager.

In a recent Survey report by the writer[3] some results have been presented which were intended to throw further light on conditions governing the deposition of salts from solution and thus to aid in solving the problem of extracting potash from American natural brines. Solutions prepared in the laboratory were employed in the experiments. Simple salt mixtures were used at first, and by gradually including other salts more complex brines were obtained and subjected to evaporation, although none were strictly comparable with those found in nature. It was not possible to do more than a small part of the experimental work contemplated at the time, and the results were presented as a first chapter in the study of the general subject of potash brines. Some of the data obtained are significant and suggest the importance of a more thorough investigation of the subject.

As a continuation of the experiments just mentioned, the natural brine from Searles Lake, Cal., has been subjected to fractional evaporation and crystallization, and the effect determined by analyzing the crystals that separated from the solution. The results are presented in the present paper as a second contribution in the study of potash brines. It is hoped that they may be of value in developing an economical process for the extraction of the commercial salts from American brines and also in studying those general geologic problems with which the deposition of salts from solution is connected.

[1] For a detailed description of this so-called lake, see Gale, H. S., Salines in the Owens, Searles, and Panamint basins, southeastern California: U. S. Geol. Survey Bull. 580, pp. 265-317, 1914 (Bull. 580-L).

[2] Gale, H. S., op. cit., p. 274.

[3] Hicks, W. B., Evaporation of potash brines: U. S. Geol. Survey Prof. Paper 95, pp. 64-72, 1915 (Prof. Paper 95-E).

Because of the acute condition in the potash situation and the eagerness with which economical methods for the extraction of potash from brines are sought, it seems desirable to give to the public as rapidly as possible all information bearing on the subject. This has led to the publication of this paper at the present time, although only a small part of the experimental work planned has been done. The results here set forth may be supplemented later.

THE BRINE.

Six samples of brine from Searles Lake were collected May 14, 1912, by R. B. Dole, and were preserved in sealed glass bottles. Each sample represented about equal quantities of brine from several wells as indicated below:

Samples of brine from Searles Lake, Cal.

No.	Source.	Location.[a]	Depth.
			Feet.
	Brine at surface	SW. ¼ sec. 15	2
1	Well S. E. V	do	20
	Well S. E. IV	NE. ¼ sec. 23	20
	Well B	SE. ¼ sec. 15	30
2	Well A	NE. ¼ sec. 22	25
	Well S. E. VI	Center sec. 22	30
	Well E. 6	SW. ¼ sec. 22	(?)
3	Well S. E. 6	Center sec. 23	(?)
	Well E. 8	SW. ¼ sec. 23	Deep.
	Well F	NE. ¼ sec. 26	Shallow.
	Well S. E. 3	NW. ¼ sec. 25	Deep.
4	Well S. E. 4	NE. ¼ sec. 25	Very deep.
	Well S. E. 8	SE. ¼ sec. 25	Very deep.
	Well E. 9	NW. ¼ sec. 30[b]	Deep.
	Well E. 10	NE. ¼ sec. 31[b]	10
	Well E. 11	SE. ¼ sec. 36	Very deep.
	Well E. 13	SW. ¼ sec. 36	Deepest.
	Well S. E. 2	SE. ¼ sec. 26	Deep.
5	Well S. E. I	SW. ¼ sec. 27	Very deep.
	Well N	NW. ¼ sec. 31[b]	6
	Well T	SW. ¼ sec. 28	Deep.
	Well U	NW. ¼ sec. 28	Very deep.
6	Well S. E. I	SW. ¼ sec. 27	Deep.

[a] All in T. 25 S., R. 43 E., except as otherwise indicated.
[b] In T. 25 S., R. 44 E.

In October, 1914, the writer prepared a composite sample of brine consisting of 1 liter from each of the six bottles described above. The brine was filtered from the suspended matter, thoroughly mixed, and preserved in a large bottle closed with a rubber stopper. When this solution was allowed to stand crystals were slowly deposited from it. These crystals would not redissolve readily on warming and shaking. In April, 1915, the brine was filtered at 22.5° C., and both the crystals and the solution were analyzed. The crystals, collected on a Monroe crucible and dried by suction, weighed 18 grams. Microscopic examination by W. T. Schaller showed that the crystals were composed largely of a mixture of sodium chloride and borax. This was confirmed by analysis, which gave the following results:

Analysis of crystals deposited by composite sample of brine from Searles Lake, Cal.

Na	21.26
K	.29
Cl	22.25
SO_4	.49
B_4O_7	22.51
CO_3	.40
H_2O (by difference)	32.80
	100.00

Accordingly the 18 grams of crystals deposited from 6 liters (7.763 grams) of brine contained only 4 grams of borate and like quantities of both sodium and chlorine. Therefore the quantity of each of these three constituents deposited represents only 0.05 per cent of the original solution, which is probably about the limit of error in the analysis and does not appreciably affect the accuracy of the analysis of the original brine.

The filtered brine which was used in the present investigation had a straw-yellow color and a cloudy appearance. The composition is given below along with that of other brines from Searles Lake for comparison.

Composition of brines from Searles Lake, Cal.

	A	B	C
K	6.17	6.34	6.07
Na	33.66	33.80	33.61
Cl	36.36	37.04	37.10
SO_4	12.86	13.00	12.99
CO_3 [a]	7.72	7.24	6.71
B_4O_7	3.23	2.50	3.01
Other constituents (Li, Mg, Al_2O_3, Fe_2O_3, SiO_2, Br, I, PO_4, As_2O_3, etc.)	(?)	.08	.51
	100.00	100.00	100.00
Total salts by summation	34.04	33.91	[b] 32.90
Specific gravity	1.2938 at 23°C	1.2974 at (?)	

[a] This represents the combined carbonates and bicarbonates. The amount of HCO_3 in the original brine found by Ross was 0.55 per cent.
[b] Approximate. The specific gravity of this sample was not reported, and the original analysis was stated in grams per liter.

A. Composite sample of brine prepared by the writer as described above and used in the present investigation. W. B. Hicks, analyst.

B. Average of six analyses of brines from wells in Searles Lake. Walton Van Winkle, analyst. Gale, H. S., op. cit., p. 277.

C. Analysis of brine from Searles Lake. W. H. Ross, analyst. Gale, H. S., op. cit., p. 277.

NOTE. B and C have been recalculated to 100 per cent.

METHODS.

METHOD OF EXPERIMENTATION.

In conducting the experiments 1,000 grams of brine continuously stirred in a beaker was evaporated on the steam bath at about 78° C. to approximately two-thirds of its original volume, and the hot solution was then separated from the deposited crystals by filtration through a paper filter supported by a platinum cone and contained in a funnel surrounded by a steam coil of brass to maintain the temperature of the steam bath during filtration. As much as possible of the adhering mother liquor was removed by strong suction, and the main bulk of the crystals were transferred to a small tared flask and weighed. The remainder of the crystals, which adhered to the beaker, filter paper, etc., were washed into a tared platinum dish, evaporated to dryness, and weighed. The combined weights so obtained represent the amount of salts deposited during the first stage of the evaporation. The two portions of the crystals were then combined and thoroughly mixed. The sample so prepared was designated 1 A and was preserved in a paraffin-sealed flask for analysis.

The filtrate, well covered to prevent evaporation, was placed in a bath having a constant temperature of 30° C. (±0.05°) and was stirred vigorously until the temperature of the solution adjusted itself to that of the thermostat and for an hour or so thereafter. The deposited crystals were allowed to settle and were then separated from the solution by filtration through paper at room temperature (approximately 30° C.) and dried as much as possible by strong suction. The main bulk of the crystals were then transferred to a small tared flask and weighed. Those adhering to the beaker, filter paper, etc., were washed into a weighed platinum dish, evaporated to dryness, and weighed. The combined weights so obtained represent the amount of salts deposited during cooling from 78° C. to 30° C. in the first stage of the evaporation. The two portions of the crystals were then combined and thoroughly mixed. The sample so prepared was designated 1 B and was preserved in a paraffin-sealed flask for analysis.

The filtrate obtained in the last operation from sample 1 B was weighed, and its specific gravity was determined by means of the Westphal balance. The solution adhering to the funnel, specific-gravity cylinder, etc., was washed into a platinum dish, evaporated to dryness, and weighed. This weight multiplied by 3 and added to that of the main portion of the solution gave the corrected weight of the filtrate. The residue was dissolved in as little water as possible and added to the main portion of the solution. The combined solution was returned to the steam bath for further concentration.

The process just described—fractional evaporation with consequent removal of the crystals deposited during evaporation and also those separated during cooling—was repeated at intervals until only a small portion of the solution remained. This produced fourteen fractions of crystals, representing seven stages in the evaporation. Each fraction was analyzed, as was also the final mother liquor, according to the methods described below.

METHODS OF ANALYSIS.

Weighed samples of the crystals were dissolved in water and diluted to definite volume (weighed samples of the brines were simply diluted to definite volume), and aliquots each containing roughly 0.5 gram of solids were taken for analysis. The determinations were made in duplicate, and practically all the figures given in the tables (pp. 6–7) are averages of two closely agreeing results. Common methods of analysis were usually employed, but short cuts were taken wherever possible, and a brief description of the procedure therefore seems advisable. The sulphate radicle was precipitated and weighed as barium sulphate, and potassium was estimated by the modified chlorplatinate method.[1] After the sample had been acidified with hydrochloric acid and the borates removed by repeated evaporation with methyl alcohol and hydrochloric acid, sodium was determined by weighing the combined bases as sulphates (after igniting to constant weight with ammonium carbonate) and subtracting the potassium sulphate. Chlorine was determined by titration with N/10 silver nitrate after neutralizing the solution with nitric acid, and the borate radicle was estimated by titration with N/10 sodium hydroxide in the presence of mannite and

[1] Hicks, W. B., A rapid modified chlorplatinate method for the estimation of potassium: Jour. Ind. Eng. Chem., vol. 5, pp. 650–653, 1913.

phenolphthalein. The carbonate radicle was determined by titrating with N/10 hydrochloric acid in the presence of methyl orange and subtracting the borate equivalent, and therefore the results include both carbonates and bicarbonates. The latter were not evaluated. Other constituents that have been reported in traces or in very small amount in the brine were disregarded.

RESULTS.

SUMMARY OF STAGES IN THE EVAPORATION.

By conducting the experiments according to the methods above described, fourteen fractions

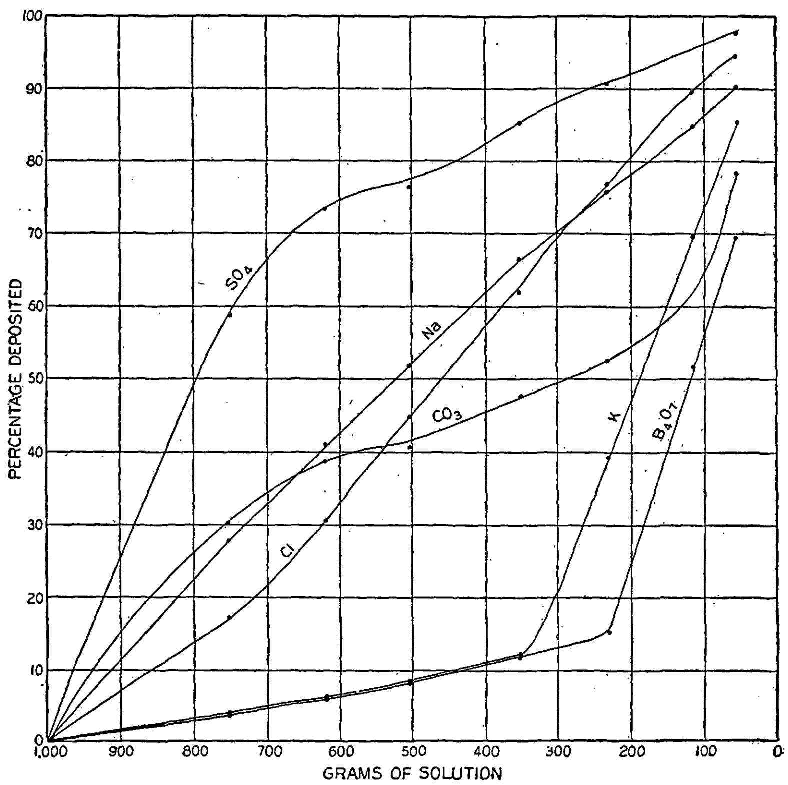


FIGURE 1.—Diagram showing the percentages of the various constituents deposited during evaporation of brine from Searles Lake, Cal.

of crystals, representing seven stages in the evaporation, were obtained. A summary of the procedure followed is given below, together with the quantity of salts making up the several fractions and the weight and specific gravity of the solution remaining after each stage in the evaporation.

First stage.—1,000 grams of brine from Searles Lake was evaporated on the steam bath at 78° C. to about two-thirds of the original volume, and during this process 75.00 grams of salts, which were designated 1 A, separated from the hot solution. On cooling from 78° to 30° C., 19.11 grams additional were deposited, which were marked 1 B. The filtrate that was separated from the crystals had a specific gravity of 1.278 at 30° C. and weighed 750 grams.

Second stage.—The 750 grams of solution remaining from the first operation was concentrated on the steam bath to about two-thirds of the original volume, and 28.93 grams of solids were deposited. The crystals so obtained were designated 2 A. When the filtrate was cooled from 78° to 30° C., 14.30 grams of solids, marked 2 B, were deposited. The filtrate remaining after the separation of the crystals had a specific gravity of 1.282 at 30° C. and weighed 617 grams.

Third stage.—The 617 grams of solution obtained in the second stage was concentrated on the steam bath at 78° C. to about 500 cubic centimeters. During this treatment 21.52 grams of salts, designated 3 A, separated from the hot solution. The solution was then cooled from 78° to 30° C., when an additional deposition of 13.56 grams occurred. This lot was designated 3 B. The filtrate that was separated from the crystals had a specific gravity of 1.295 at 30° C. and weighed 502 grams.

Fourth stage.—The filtrate from the third stage, amounting to 502 grams, was evaporated to about two-thirds its volume on the steam bath at 78° C., resulting in the separation from the hot solution of 41.01 grams of salt, designated 4 A. When the solution was cooled from 78° to 30° C., 8.88 grams of crystals separated. These were marked 4 B. The filtrate remaining had a specific gravity of 1.318 at 30° C. and weighed 351 grams.

Fifth stage.—The 351 grams of solution obtained as indicated above was evaporated to about 200 cubic centimeters on the steam bath at 78° C., and during this process 28.81 grams of crystals were deposited from the hot solution. These were designated 5 A. Cooling from 78° to 30° C. resulted in the deposition of 14.31 grams of crystals, designated 5 B. The solution that was separated from the crystals had a specific gravity of 1.351 and weighed 230 grams.

Sixth stage.—The filtrate remaining from the fifth operation, which amounted to 230 grams, was concentrated on the steam bath at 78° C. to about 100 cubic centimeters. The salts deposited during the evaporation from the hot solution weighed 24.68 grams and were designated 6 A. Those deposited during cooling from 78° to 30° C. weighed 29.37 grams and were designated 6 B. The filtrate had a specific gravity of 1.386 at 30° C. and weighed 114 grams.

Seventh stage.—The 114 grams of solution obtained as described above was evaporated on the steam bath at 78° C. to about 50 cubic centimeters, and the salts deposited during this operation from the hot solution weighed 19.22 grams and were designated 7 A. The crystals that separated on the cooling of the solution from 78° to 30° C. weighed 10.41 grams and were marked 7 B.

The solution that was separated from the crystals had a specific gravity of 1.399 at 30° C. and weighed 55 grams. This solution represents the final filtrate, indicated in Tables 1, 2, and 3 by the number 8.

TABULATION OF RESULTS.

Each of the fractions of crystals obtained in the experiments just detailed was analyzed, as was also the final filtrate. The results are given in Table 1 and have been used in computing the hypothetical combinations given in Table 2. The figures in Table 2 were obtained by calculating all the potassium to potassium chloride and the borate, carbonate, and sulphate radicles to the corresponding sodium salts and supplying enough sodium chloride to make the results add up to 100. Although this method of computation conceals the small error of closure, it was used because of its simplicity. The percentages of the several constituents deposited from solution as evaporation progressed have been calculated and are set forth in Table 3 and shown graphically in figure 1. The composition of the solution remaining after each stage in the evaporation has been computed from the quantity and composition of the various fractions of crystals, the final filtrate being used as a basis. The data so obtained, together with the composition of the original brine and that of the final mother liquor, are presented in Table 4. These values, which give the changes in the composition of the solution resulting through evaporation, have been plotted and are shown graphically in figure 2.

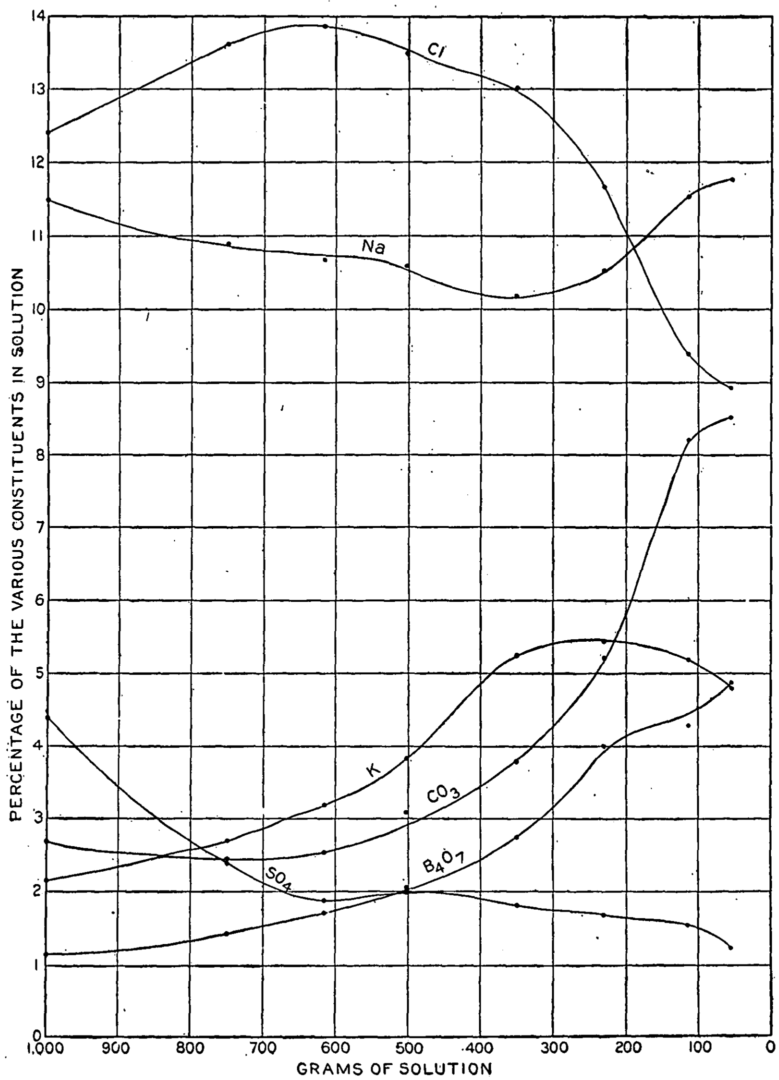


FIGURE 2.—Diagram showing the changes in the composition of the solution resulting through evaporation of brine from Searles Lake, Cal.

Nos. 1 to 8 in the tables represent the successive stages in the evaporation. The letter A refers to the crystals deposited from the hot solution during the process of evaporation; B has reference to the crystals deposited as the solution was cooled from 78° to 30° C.

TABLE 1.—*Percentage composition, in radicles, of the crystals deposited during fractional evaporation.*

	1		2		3		4		5		6		7		8
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	
K	0.96	0.72	1.14	0.87	1.54	1.37	1.72	1.78	1.95	40.35	3.21	30.03	5.29	31.68	11.97
Na	35.45	38.61	36.51	38.71	37.28	37.94	37.00	37.58	37.27	8.87	36.04	12.87	35.60	12.14	29.36
Cl	14.73	59.92	30.22	59.43	50.99	58.99	45.20	58.98	46.76	47.92	44.03	31.10	21.64	32.51	22.33
SO_4	36.98	.22	23.51	.28	6.60	.47	10.49	.31	9.16	.39	8.55	1.03	6.71	.77	3.07
CO_3	11.34	.21	8.03	.31	2.90	.53	4.68	.52	3.99	1.36	6.54	5.57	26.83	4.96	21.23
B_4O_7	.54	.32	.59	.40	.69	.70	.91	.83	.87	1.11	1.63	19.40	3.93	17.94	12.04
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	[a] 100.00
H_2O by difference	7.60	3.89	6.74	3.18	8.64	6.36	11.72	2.34	8.21	9.60	8.67	35.21	23.59	28.99	59.91
Anhydrous salts:															
By summation	92.40	96.11	93.26	96.82	91.36	93.64	88.28	97.66	91.79	90.40	91.33	64.79	76.41	71.01	40.09
Ignited residue	92.20	95.70	93.05	96.40	91.50	93.30	88.40	97.60	92.20	90.35	91.00	64.15	76.10	71.20	40.80
Weight of crystals, grams	75.00	19.11	28.93	14.30	21.52	13.56	41.01	8.88	28.81	14.31	24.68	29.37	19.22	10.41	....

[a] The solution also contained 0.22 per cent arsenic=0.55 per cent of the anhydrous salts.

TABLE 2.—*Percentage composition, in hypothetical combinations, of the crystals deposited during fractional evaporation.*

	1		2		3		4		5		6		7		8
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	
KCl	1.83	1.37	2.17	1.66	2.93	2.61	3.28	3.39	3.72	76.90	6.12	57.25	10.08	60.37	22.80
NaCl	22.72	97.52	48.09	96.86	81.29	94.84	71.67	94.56	74.56	18.68	67.57	6.28	27.49	6.54	19.58
Na_2SO_4	54.75	.33	34.81	.41	9.77	.70	15.51	.46	13.56	.58	12.65	1.53	9.94	1.14	4.54
Na_2CO_3	20.00	.37	14.17	.55	5.12	.94	8.26	.52	7.04	2.40	11.55	9.84	47.40	8.75	37.50
$Na_2B_4O_7$	.70	.41	.76	.52	.89	.91	1.18	1.07	1.12	1.44	2.11	25.10	5.09	23.20	15.58
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 3.—*Percentages of the constituents deposited during fractional evaporation.*

[The first column for each constituent gives the percentage deposited at each stage; the second column gives the total percentage.]

Stage.	K.		Na.		Cl.		SO_4.		CO_3.		B_4O_7.	
1 A	3.19	3.19	21.44	21.44	8.23	8.23	58.50	58.50	29.88	29.88	3.36	3.36
1 B	.62	3.81	6.19	27.63	8.90	17.13	.09	58.59	.15	30.03	.55	3.91
2 A	1.48	5.29	8.59	36.22	6.60	23.73	14.47	73.06	8.25	38.28	1.45	5.36
2 B	.57	5.86	4.68	40.90	6.65	30.38	.09	73.15	.15	38.43	.55	5.91
3 A	1.43	7.29	6.40	47.30	8.10	38.48	2.97	76.12	2.17	40.60	1.27	7.18
3 B	.81	8.10	4.20	51.50	6.05	44.53	.14	76.26	.27	40.87	.82	8.00
4 A	2.95	11.05	11.68	63.18	13.22	57.75	8.68	84.94	6.43	47.30	3.00	11.00
4 B	.71	11.76	2.84	66.02	4.13	61.88	.07	85.01	.19	47.49	.64	11.64
5 A	2.48	14.24	8.61	74.63	10.00	71.88	5.52	90.53	3.99	51.48	2.09	13.73
5 B	24.85	39.09	1.00	75.63	5.01	76.89	.11	90.64	.68	52.16	1.27	15.00
6 A	3.43	42.52	7.08	82.71	8.02	84.91	4.38	95.02	5.63	57.79	3.36	18.36
6 B	27.22	69.74	2.14	84.85	4.79	89.70	.46	95.48	4.03	61.82	33.51	51.87
7 A	3.71	73.45	4.56	89.41	2.57	92.27	2.26	97.74	14.97	76.79	5.28	57.15
7 B	11.14	84.59	.79	90.20	1.94	94.21	.14	97.88	1.41	78.20	12.09	69.24
8	12.57	97.16	5.66	95.86	3.98	98.19	1.55	99.43	17.80	96.00	24.20	93.44

TABLE 4.—*Changes in the composition of the solution during fractional evaporation.*

Stage.	Solution after evaporation (grams).	Specific gravity at $\frac{30° C.}{20° C.}$	Percentage composition of the solution (calculated).							Potassium in total salts (per cent).	K/Na ratio.
			K.	Na.	Cl.	SO_4.	CO_3.	B_4O_7.	Total.		
Original solution [a]	1,000	1.292	2.10	11.46	12.37	4.38	2.63	1.10	34.04	6.16	0.18
1	750	1.278	2.69	10.88	13.60	2.39	2.41	1.40	33.37	8.06	.25
2	617	1.282	3.19	10.66	13.85	1.87	2.55	1.67	33.79	9.44	.30
3	502	1.295	3.84	10.57	13.46	2.03	3.10	2.00	35.00	10 97	.36
4	351	1.318	5.26	10.17	13.04	1.81	3.79	2.74	36.81	14.30	.52
5	230	1.351	5.45	10.50	11.66	1.68	5.22	4.01	38.52	14.15	.52
6	114	1.386	5.20	11.54	9.39	1.53	8.21	4.29	40.16	12.95	.45
7 [a]	55	1.399	4.80	11.77	8.95	1.23	8.51	4.83	40.09	11.97	.41

[a] Values determined by actual analysis.

DISCUSSION.

Before discussing the results presented in the tables, it will be well to recall the fact that before the fractional crystallization began sodium chloride and borax had been deposited from the brine on standing at 22.5° C. Although undetermined factors make deductions inconclusive, the facts indicate that when the temperature is lowered these constituents must separate from the solution in order that equilibrium may be attained for the new conditions. It might be inferred that by lowering the temperature still further larger amounts of sodium chloride and borax would leave the solution. However, as the solubility of sodium sulphate decreases rapidly when the temperature is lowered below the transition point, this constituent might separate out in large amounts at low temperature. In principle the same argument may be applied to the potassium chloride and sodium carbonate contained in the brine. The final equilibrium at any temperature is dependent on the solid phases which separate and must therefore be determined experimentally.

By reference to the tables it will be seen that more than 58 per cent of all the sulphate originally present in the brine was deposited from the hot solution in the first fraction of crystals, which is composed of nearly 55 per cent of sodium sulphate, large amounts of carbonate and chloride, and only small amounts of borate and salts of potassium. In the other fractions of crystals that were deposited from the hot solution as evaporation progressed the sulphate radicle is a chief component. When the brine had been reduced to half its original volume, more than 76 per cent of all the sulphate had been deposited, and in the final filtrate less than 2 per cent of it remained. It is significant that only small quantities of sulphate were found in the several fractions of crystals deposited as the solution was cooled from 78° to 30° C. These facts point to the conclusion that sodium sulphate is less soluble in the hot solution than it is at 30° C., a conclusion which is in accord with experimental data on the solubility of sodium sulphate in pure water.

The behavior of the carbonate radicle was somewhat like that of the sulphate. A large portion came down in the first crop of crystals and in all the succeeding fractions that were deposited from the hot solution during evaporation (marked A in the tables). However, a considerable amount separated out during cooling from 78° to 30° C. in fractions 6 B and 7 B, and nearly 18 per cent of the total amount in the original brine remained in the final filtrate. The results are somewhat difficult to interpret but point out clearly that the carbonate is at least as soluble in the cold solution as in the hot until about the fifth stage in the evaporation. Then, in the presence of a greater concentration of potassium, the carbonate is much more soluble in the hot solution.

At this point it seems pertinent to call attention to an experiment conducted by the writer with the view of showing the possibility of removing the carbonate from the brine by the action of carbon dioxide. This gas was passed at the rate of several bubbles a second through 100 grams of the brine at room temperature. No visible action was apparent for some time. Finally a precipitate began to form and to adhere to the bottom and sides of the container. After about six hours no further action was perceptible and the reaction appeared to be completed. The residue, which was filtered from the solution through a tared Monroe crucible, weighed 5.85 grams. It was analyzed with the following results:

Analysis of precipitate produced through action of carbon dioxide on brine.

Na	26.27
K	.68
Cl	4.28
SO_4	.65
CO_3	4.13
HCO_3	53.36
B_4O_7	1.06
H_2O (by difference)	9.57
	100.00

The solids which separated through the action of carbon dioxide on the brine contained 73.6 per cent of sodium bicarbonate and 9.57 per cent of water. The original brine contained 2.63 per cent of CO_3, and so the deposition represents 67.5 per cent of all the carbonate originally present in the brine.

Small amounts of borate separated from the hot solution and also during cooling in all the fractions of crystals, but at the beginning of the sixth stage in the evaporation, when only 114 grams of the solution remained, the total quantity of borate that had been deposited was only about 18 per cent of the amount originally present. More than 45 per cent of the borate separated in the two fractions 6 B and 7 B as the solution was cooled from 78° to 30° C., and more than 24 per cent remained in the final filtrate. The results show that the borate became more soluble in the solution as the concentration of the potassium and carbonate radicles increased and that of chloride and sulphate decreased.

Although potassium separated in increasing amounts in all the succeeding fractions of crystals up to the fifth stage, only about 8 per cent of that originally present was lost from solution by reducing it to half the original volume and increasing the concentration of the potassium to nearly 4 per cent. This loss is somewhat higher than that recorded in the experiments with artificial potash brines.[1]

More than 60 per cent of all the potassium was deposited on cooling the solution from 78° to 30° C. in fractions 5 B, 6 B, and 7 B, and 12.57 per cent remained in the final filtrate. Residue 5 B, representing 24.85 per cent of all the potassium in the original brine, contained the equivalent of 76.9 per cent of potassium chloride, with sodium chloride as the principal impurity. Residues 6 B and 7 B, representing more than 48 per cent of all the potassium in the brine, contained 57 and 60 per cent, respectively, of potassium chloride, but in these residues carbonates and borates are the chief impurities.

The data here recorded indicate that carefully controlled fractional evaporation and crystallization, possibly combined with other treatment, promise much as a means of obtaining potassium from brines similar to that of Searles Lake. A wider range of temperature suggests itself at once, and other possibilities are apparent. However, many points in regard to the behavior of the constituents of the brine under varying conditions remain to be studied before the problem can be adequately discussed.

[1] Hicks, W. B., Evaporation of potash brines: U. S. Geol. Survey Prof. Paper 95, pp. 65–72, 1915 (Prof. Paper 95–E).

RELATION OF THE WISSAHICKON MICA GNEISS TO THE SHENANDOAH LIMESTONE AND OCTORARO SCHIST OF THE DOE RUN AND AVONDALE REGION, CHESTER COUNTY, PENNSYLVANIA.

By Eleanora F. Bliss and Anna I. Jonas.

AREA DISCUSSED.

The region discussed in this paper lies in Chester County, Pa., and is included in the eastern half of the Coatesville quadrangle. (See fig. 3.) It is within the belt of crystalline schists and gneisses of the Piedmont Plateau. The northern half of the area, which will be called the Doe Run region, from the village of that name (see fig. 4, p. 15), has been surveyed by Eleanora F. Bliss in connection with the problem of the relation of the Wissahickon mica gneiss to the Octoraro schist. The southern half, the Avondale region (see fig. 5, p. 17), has been studied by Anna I. Jonas in order to determine the relation of the Wissahickon mica gneiss to the Shenandoah limestone.

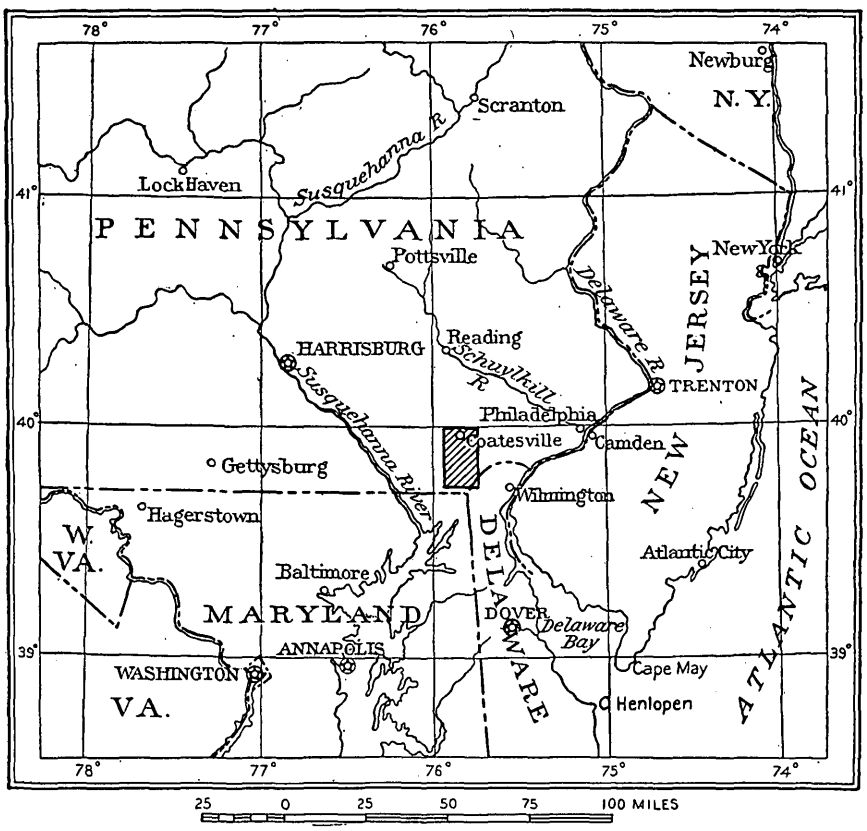


Figure 3.—Index map showing location of Doe Run and Avondale region, Chester County, Pa.

The field work was done during parts of the summers of 1906 and 1909 in connection with a thesis problem at Bryn Mawr College, under the direction of Miss Florence Bascom, professor of geology at Bryn Mawr, to whom thanks are due for criticism and assistance in the preparation of the results for publication.

Approximate correlation of sedimentary formations of Doe Run and Avondale region, Pennsylvania.

Geologic age.	Southern Appalachian region. Keith. Nantahala folio.	Southern Appalachian region. Keith. Roan Mountain folio.	Southern Appalachian region. Campbell (Bristol folio).	Southern Appalachian region. Darton (Franklin, Monterey, and Staunton folios).	Harpers Ferry region: Keith (Harpers Ferry folio).	District of Columbia: Keith (Washington folio).	Doe Run and Avondale region, Pennsylvania: Bliss and Jonas (this paper).	Philadelphia region: Bascom (Philadelphia folio).	New Jersey. Bascom (Trenton folio).	New Jersey. Spencer and Kümmel (Franklin Furnace folio).	New Jersey. Darton and Bayley (Passaic folio).	New York City and vicinity: Merrill (New York City folio).	New England: Pumpelly, Wolff, and Dale (Monograph 23).	
Ordovician.		Athens shale.	Athens shale.	Martinsburg shale.	Martinsburg shale.	Absent.	Octoraro schist.	Octoraro schist.	Absent.	Martinsburg shale.	Hudson schist.	Hudson schist.	Greylock schist. Bellowspipe limestone. Berkshire schist.	Rowe schist. Hoosac schist.
		Absent.	Chickamauga limestone.	Shenandoah limestone.	Shenandoah limestone.	Absent.	Shenandoah limestone.	Shenandoah limestone.	Shenandoah limestone.	Jacksonburg limestone.	Absent.	Stockbridge dolomite.	Stockbridge limestone.	
Cambrian.		Knox dolomite.	Knox dolomite.							Kittatinny limestone.				
		Nolichucky shale.	Nolichucky shale.											
		Honaker limestone.	Honaker limestone.											
	Nottely quartzite. Andrews schist.	Watauga shale.	Russell formation.											
	Murphy marble.	Shady limestone.	Absent.											
	Valleytown formation.	Erwin quartzite.	Absent.	Absent.	Antietam sandstone.	Absent.	Chickies formation.	Chickies quartzite.	Chickies quartzite.	Hardyston quartzite.	Absent.	Poughquag quartzite.	Vermont quartzite.	
	Brasstown schist. Tusquitee quartzite. Nantahala slate.	Hampton shale.	Hampton shale.		Harpers shale.									
	Great Smoky conglomerate. Hiwassee slate.	Unicoi formation.	Unicoi formation.		Weverton sandstone. Loudoun formation.									
Unconformity														
Pre-Cambrian.	Carolina gneiss.	Carolina gneiss.				Carolina gneiss.	Wissahickon mica gneiss.	Wissahickon mica gneiss.	Franklin limestone.	Franklin limestone.	Franklin limestone.			
									Wissahickon mica gneiss.					
							Baltimore gneiss.	Baltimore gneiss.	Baltimore gneiss.		Garnetiferous graphite schist.	Fordham gneiss.		

DESCRIPTIVE GEOLOGY.

GENERAL RELATIONS.

All the rocks of this region have a like geologic history. The formations consist of metamorphic rocks, ranging in age from pre-Cambrian to Ordovician, and all of them are cut by fresh diabase dikes of the Triassic period. The high degree of metamorphism shown by the rocks of the region is characteristic of the formations of the southeastern part of the Piedmont Plateau as contrasted with those of the northwestern part, where dynamic action was less effective than in the southeast.

The succession of formations in the Coatesville quadrangle is as follows:

Metamorphic rocks:
- Ordovician: Octoraro schist.
- Cambrian and Ordovician: Shenandoah limestone.
- Cambrian: Chickies formation.
- Pre-Cambrian:
  - Wissahickon mica gneiss.
  - Baltimore gneiss.

Igneous rocks:
- Triassic: Diabase.
- Pre-Silurian or younger:
  - Pegmatite.
  - Serpentine.
- Early Cambrian or older: Metagabbro.

The Baltimore gneiss is a part of the pre-Cambrian floor upon which the Paleozoic sediments were laid down. The Lower Cambrian represents coarse arenaceous sediments that were irregularly deposited on this floor. After the accumulation of these deposits the calcareous materials of the Cambrian and Ordovician periods were laid down and subsequently covered by clays of Ordovician age. These sediments have been altered in character, structure, and extent by compression, folding, uplift, and erosion. During Triassic time they were partly submerged, and gravel, sand, and clay were spread over the old eroded surface; these materials, in turn, have suffered partial removal by erosion, which cut through the Paleozoic rocks to the pre-Cambrian gneiss of the original floor.

The accompanying table shows the correlation of these formations with the rocks of New England, eastern New York, Maryland, Virginia, and the southern Appalachian region. The distribution of these formations in the Doe Run and Avondale region is shown on Plate I.

It may be of interest to note the work of earlier investigators in the Philadelphia region. Conclusions on these formations published by the First and Second geological surveys of Pennsylvania are somewhat similar to each other.

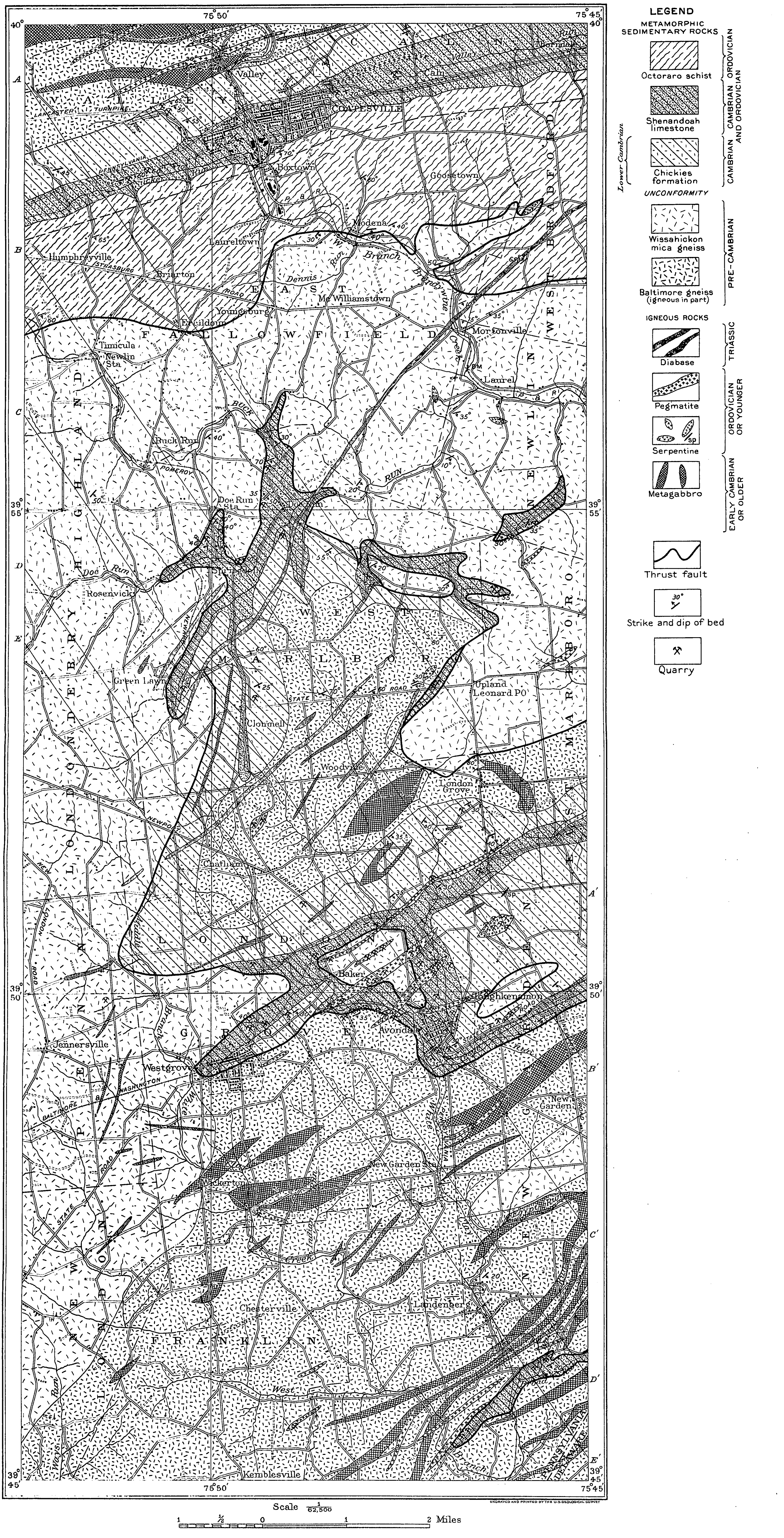
H. D. Rogers,[1] of the First Geological Survey, included all the gneisses (the Baltimore gneiss, the Wissahickon mica gneiss, and the granite, gabbro, and hornblende gneisses) in the older crystalline gneissic strata, which he grouped in three belts exposed in section on Schuylkill River from Grays Ferry, in Philadelphia, northward to Spring Mill. The first and second gneiss belts include the Wissahickon mica gneiss and an intrusive granite gneiss; the third belt represents the Baltimore gneiss. He called the Chickies formation "Primal white sandstone," which he made equivalent to the Potsdam or Upper Cambrian of New York; the Shenandoah limestone he called "Auroral magnesian limestone," which he correlated with the Chazy and Black River limestones of New York; the Octoraro schist he called "Primal upper slate" and placed over the "Primal sandstone."

C. E. Hall,[2] of the Second Geological Survey, substituted the terms "Eozoic," "Azoic gneiss," and "Laurentian syenite" for the third belt and separated the first and second belts, beginning at the base, into "Philadelphia schists and gneisses" and "Chestnut Hill garnetiferous schists." The quartzite he called "Potsdam, formation No. 1"; the Shenandoah limestone, "formation No. 2," described as representing the "Calciferous and Trenton groups"; the Octoraro schist is his "formation No. 3," described as representing the "Hudson River group." The Octoraro schist is described by T. D. Rand[3] under the term "hydro-mica schist."

[1] Pennsylvania First Geol. Survey Rept., vol. 1, pp. 66–82, 122–183, 1858.

[2] Pennsylvania Second Geol. Survey Rept., C6, pp. 1–47, 1881.

[3] Rand, T. D., Notes on the geology of Radnor Township, in Delaware County, Pa., and of the townships adjacent: Pennsylvania Geol. Survey Ann. Rept., 1886, pt. 4, p. 1580, 1887.



GEOLOGIC MAP OF DOE RUN AND AVONDALE REGION, CHESTER COUNTY, PA.

METAMORPHIC ROCKS.

PRE-CAMBRIAN.

BALTIMORE GNEISS.

Distribution.—In the Doe Run and Avondale region the Baltimore gneiss has a wide distribution at the surface: it occurs in three areas, one of which extends into both parts of the region. The most northerly area is north of Chester Valley, where gneiss underlies the northwest corner of the region and extends parallel to the strike from a point about a mile north of Caln southwestward to the western boundary of the area shown on the map. The second area, which is somewhat ellipsoidal in shape with its longest diameter extending in a northeasterly direction, lies in the central part of the Doe Run and Avondale region. Its northeast end is half a mile north of Upland, and its southwest end is a mile southwest of Chatham. The southernmost area extends south of the towns of Avondale and Westgrove to the southern boundary of the quadrangle. In this southern area it has been found difficult to make a satisfactory lithologic separation between the Baltimore gneiss and the Wissahickon mica gneiss and it may be eventually found that some of the rock mapped as Baltimore gneiss may prove to be Wissahickon gneiss.

Field relations.—The boundaries of the Baltimore gneiss are formed by younger formations—the pre-Cambrian Wissahickon mica gneiss, the Cambrian Chickies formation, or the Shenandoah limestone. The formation is penetrated by dikes of pegmatite and diabase, the latter intruded parallel to the strike of the country rock. The average strike of the Baltimore gneiss is N. 60° E., and the dip of the schistosity 30° SE. Its structure can be observed in stream gorges, in road cuts, and in the railroad cuts about Landenberg. The Baltimore gneiss produces a fertile soil, though it is made stony by the presence of slabs of the gneiss, which are colored a yellowish brown by iron oxide. South of Avondale, owing to a change in the character of the gneiss, the soil is sandy, dark colored, and full of black biotite.

Lithologic character.—The rock is a medium-grained crystalline, massive or banded gneiss composed of quartz, feldspar, biotite, and hornblende. The relative amount of each constituent varies widely; biotite may be abundant or scanty; hornblende may be present with the biotite or may replace it. The more or less partial segregation of the leucocratic and melanocratic constituents in alternating layers gives the rock the gneissic structure. In many exposures the rock is entirely disintegrated but has the gneissic structure still preserved; the kaolinized feldspar shows in white bands defined by the dark constituents of the rock.

The Baltimore gneiss is composed of an igneous and a sedimentary facies which it has been found impossible to separate in mapping. The igneous facies occurs in the center of the Baltimore gneiss area north of Coatesville and in a few scattered bowlders a mile southeast of Springdell and about a mile south of Clonmell. This rock weathers into spheroidal bowlders and lacks the banding which is characteristic of the main mass of the Baltimore gneiss in this region. The sedimentary facies is a light-gray banded gneiss containing considerable quartz and a varying amount of melanocratic constituents; a micaceous variety occurs in which the mica is abundantly developed along planes of schistosity. Thin sections of the sedimentary Baltimore gneiss show the accessory minerals apatite, zircon, and magnetite in slightly rounded or waterworn forms. Quartz in a hornstone structure emphasized by iron oxide stain forms a groundmass in which are small blades of brown biotite whose longer axes have a generally parallel orientation. Feldspar occurs in fresh xenomorphic individuals of orthoclase, microcline, and oligoclase.

Analyses.—The following analyses were made on specimens of the Baltimore gneiss outside of the Avondale region—No. 1 representing samples obtained at six localities in the Philadelphia region and Nos. 2 and 3 the Baltimore gneiss of the Germantown quadrangle, where only the igneous facies is found. The analyses with low alumina, lime greater than magnesia, and soda greater than potassa indicate a rock of igneous character.

Analyses of Baltimore gneiss.

	1	2	3
SiO_2	70.21	72.99	63.93
Al_2O_3	13.95	10.90	12.02
Fe_2O_3	1.05	.55	2.40
FeO	3.08	2.50	2.95
MgO	1.26	1.07	2.44
CaO	3.10	1.88	4.00
Na_2O	3.27	3.34	3.15
K_2O	2.69	1.20	.84
H_2O+	.48	1.47	1.30
H_2O-	.19	....	....
CO_2	.11	C 1.13	.51
TiO_2	.52	.84	1.04
ZrO_2	Trace.	....	....
P_2O_5	.10	.18	(a)
Cl	(b)	....	....
F	(b)	....	....
S	.09	FeS_2 1.61	Fe_7S_8 4.04
NiO	Trace.	....	Trace.
MnO	.11	....	Trace.
BaO	.09	....	CuO Trace.
SrO	Trace.	....	....
	100.30	99.66	98.62

[a] Not determined. [b] Not estimated.

1. Analysis by W. F. Hillebrand, U. S. Geological Survey. Bascom, Florence, Piedmont district of Pennsylvania: Geol. Soc. America Bull., vol. 16, p. 295, 1905.

2 and 3. Analyses by F. A. Genth, jr., Pennsylvania Second Geol. Survey Rept. C6, pp. 116, 105, 1881.

The following norm is obtained by recalculation of analysis 1:

Norm of Baltimore gneiss.

Corundum	0.20	Ilmenite	1.06
Quartz	30.48	Pyrite	.18
Orthoclase	16.68	Magnetite	1.62
Albite	27.77	H_2O	.67
Anorthite	14.46	CO_2	.11
Hypersthene	6.90		
Apatite	.34		100.47

The rock falls into Class I, order 4, rang 3, subrang 4—that is, the salic constituents are preponderant over the femic, the feldspar is dominant over the quartz, the potassa-soda percentage exceeds the lime, and finally, of the alkalies, soda is only a little in excess of the potassa. The rock is a biotitic hornblende granoyellowstonose.

The analysis of the Baltimore gneiss in its massive facies shows a rock of igneous origin. This rock is a remnant of the ancient central portion of the formation, which is found in the Baltimore gneiss of the area north of Coatesville. The Baltimore gneiss northwest of London Grove is thought to be of sedimentary origin, although derived from igneous material with little reworking. In pre-Cambrian time, by secular disintegration, such as takes place readily in a moist climate and in a country of slight topographic diversity, a soil was formed over the old igneous Baltimore gneiss land mass. By transgression of the sea the soil and underlying disintegrated rock were removed, reworked, and subsequently covered by other deposits. The rock formed by the consolidation and recrystallization of this material resembles the original rock in its constituents but possesses sedimentary rather than igneous characteristics. Folding has united the original and derived rocks into a complex that is difficult to separate into well-defined areas of igneous and sedimentary rocks. A formation similarly developed among the pre-Cambrian gneisses of Hoosac Mountain has been described by Pumpelly.[1]

Thickness.—As the Baltimore gneiss represents the remnant of the pre-Cambrian gneiss floor upon which sediments of later age were laid down, its thickness can not be estimated.

Age and correlation.—Stratigraphic relations determine the pre-Cambrian age of the Baltimore gneiss; the formation is overlain by Cambrian sediments, from which it is everywhere separated by an unconformity.

The gneiss has been called Baltimore because of its correlation with gneiss exposed at Baltimore, Md., and has been recognized as the partial equivalent of the Fordham gneiss of New York, the Stamford granite gneiss of New England, and the Carolina gneiss of the South.

WISSAHICKON MICA GNEISS.

Distribution.—The Wissahickon mica gneiss covers the western and central portions of the Doe Run and Avondale region. Its northern boundary is the contact with the Octoraro schist, a line which runs northeastward from Timicula in a direction roughly parallel to the trend of the South Valley Hills. In the central and eastern parts of the Doe Run area of the formation it surrounds several bodies of limestone and quartzite, and north of Upland it occurs in two lenses bounded by limestone and quartzite. From the northwestern part of the Avondale district, west of the Baltimore gneiss and the Paleozoic formations, the Wissahickon is exposed continuously southward to the southern boundary of the Coatesville quadrangle.

[1] Pumpelly, Raphael, The relation of secular rock disintegration to certain transitional crystalline schists: Geol. Soc. America Bull., vol 2, pp. 209-224, 1891.

Field relations.—The usual strike of the mica gneiss lies between N. 60° E. and N. 75° E. The isoclinal dip of the cleavage and of the bedding is usually southeast, the prevailing dip of the rocks of the eastern Piedmont, and the average angle of dip is 35°. Stratification is a pronounced feature of the formation, and the strata are usually crumpled. In addition to cleavage planes transverse to the fine crumpling of the strata, the mica gneiss has four systems of joint planes, parallel to which the rock breaks readily; thus it never weathers into bowlders but into angular fragments, producing a loamy clay soil full of rock fragments, of mica, and, in many localities, of garnets. From Jennersville southward through Kelton to the border of the quadrangle and eastward to Wickerton the soil is red, sandy, and sparkling with muscovite.

Although the Wissahickon gneiss crops out in many places, it weathers so readily as to afford few fresh exposures. It is generally exposed along stream beds, in road cuts, or in weathered cliffs projecting from hillsides that are covered by a mantle of heavy soil. It breaks readily into splintery fragments, which have been compared in appearance to half-rotted wood.

Lithologic character.—The Wissahickon mica gneiss is a silvery-gray to greenish medium to coarse grained schistose rock characterized by abundant muscovite and a varying amount of quartz and feldspar. Muscovite is developed either in minute crystals or in large glistening crystals which give the rock a spangled appearance. Garnets are a common constituent, and tourmaline is abundant.

The mica gneiss is intruded by dikes of metagabbro and pegmatite and, in some localities, is so thoroughly injected by these intrusives as to lose its peculiar characteristics. Where free from such injections the Wissahickon mica gneiss has the appearance of a metamorphosed sediment. A change in mineral constitution exists parallel to and is a means of recognizing the primary structure or bedding; where the bedding planes are finely plicated conspicuous unplicated transverse cleavage planes render the rock schistose and obscure the primary structure.

By microscopic study the feldspar is found to be orthoclase and andesine. The rock fails to show the sequence of crystallization of constituents which is peculiar to igneous rocks, and the accessory minerals, apatite and zircon, are present in rounded grains—both facts that point to a sedimentary origin for the rock. The absence of pressure effects in the quartz and feldspar also indicates that the rock is a recrystallized sediment.

This typical gneissic facies weathers to a greenish-brown rock in which the micaceous character is very conspicuous. It disintegrates readily, forming an argillaceous sandy soil that glistens with mica and is speckled with garnets. With local variations this gneiss, which is well exposed near Springdell in a road cut, is generally characteristic of the southern half of the main Wissahickon area.

Farther north, toward the schist boundary, the mica gneiss changes considerably in character. The fresh rock is fine grained, with bedding planes so thin that the rock assumes a schistose appearance, and the mica occurs in very fine crystals, evenly disseminated throughout the rock to such an extent as to obscure the other constituents. It weathers to a glistening green rock of schistose character, in which only the mica is visible on bedding planes, but on planes normal to the bedding the quartz and feldspar can be seen in very fine bands or in lenses wrapped about by the micaceous layers. Garnets are present in some of the rock. The weathered facies resembles the Octoraro schist, and where the two are adjacent they are difficult of separation. It differs from the schist, however, both in the presence of a characteristic crumpled bedding and also in the mode of occurrence, for it crops out along the roads and stream banks as high cliffs or strews the surface of the country in large slabs broken parallel to joint planes and contrasting with the small silvery fragments of the schist. A green slaty variety found at the northern boundary of the Wissahickon gneiss differs from the typical rock in its fine grain, extremely quartzose character, scanty feldspar, and abundant chlorite.

Analyses.—The best analysis obtainable of the mica gneiss was made by W. F. Hillebrand, of the United States Geological Survey, from four samples obtained at different localities in the Philadelphia region.[1] It is

[1] Bascom, Florence, Piedmont district of Pennsylvania: Geol. Soc. America Bull., vol. 16, p. 403, 1905.

given in column 1 of the subjoined table. Analysis 2 was made by F. A. Genth, jr., from a specimen taken along Neshaminy Creek.[1]

Analyses of Wissahickon mica gneiss.

	1	2
SiO_2	66.13	56.40
Al_2O_3	15.11	19.76
Fe_2O_3	2.52	4.35
FeO	3.19	4.40
MgO	2.42	3.11
CaO	1.87	.09
Na_2O	2.71	5.82
K_2O	2.86	1.27
H_2O+	1.55	3.37
H_2O-	.24	....
TiO_2	.82	1.05
P_2O_5	.22	.37
S	.03	....
CrO_2	None.	Trace.
MnO	.20	Trace.
BaO	Trace.	Trace.
SrO	Trace.	Trace.
	99.87	99.99

Origin.—The Wissahickon mica gneiss is considered to be a sedimentary rock whose origin has been obscured by extreme metamorphism. The rock has an original stratification, more or less perfectly preserved, which is more apparent where the cleavage, usually parallel, is discordant to the bedding. Other proofs of its sedimentary origin brought out by microscopic study have been mentioned.

That the Wissahickon mica gneiss has been derived from an arkosic argillite is to be inferred from its chemical composition. In the belt of weathering the underground and superficial waters carry materials in solution and suspension, and the materials that are easily soluble are not likely to be present in mechanical sediments, which represent the residual materials after solution has done its work more or less thoroughly and which therefore consist of members of the kaolin group, and serpentine-talc group, of quartz, aluminum oxide minerals, and acidic feldspars. An argillite, therefore, would be deficient in the alkalies and alkaline earths and more deficient in sodium and calcium than in potassium and magnesium, the percentage of alumina would be large, and after metamorphism the rock would retain its original chemical composition.

[1] Pennsylvania Second Geol. Survey Rept. C6, p. 109, 1881.

The analyses of the mica gneiss show such characters as have been described—alumina is high, magnesia is greater than lime, and potassa is greater than soda. This arkosic mud, by crystallization and metasomatism, has been metamorphosed into a mica gneiss. The feldspathic material has produced feldspar; the ferromagnesian material, muscovite; the sand has furnished the quartz, and a gneiss is the result.

Its more gneissic facies is due to injection of material parallel to the bedding. Pressure has caused reorientation of the old minerals with their longest axes in a plane normal to the pressure and the production of the new minerals with similar orientation. The muscovite, because of its perfect basal cleavage, is the mineral to which is due mainly the production of rock cleavage and fissility.

Thickness.—The thickness of the Wissahickon mica gneiss can not be exactly determined. Its isoclinal dip with repeated folding gives the impression of great thickness, but the actual thickness is difficult to estimate because the formation is an ancient pre-Cambrian gneiss bounded above by an unconformity. Its estimated thickness has been placed between 1,000 and 2,000 feet.

Age and correlation.—In the absence of fossil content the determination of the age of the Wissahickon gneiss must depend upon the stratigraphic relations, which have been much obscured in the eastern Piedmont region; these relations, which are discussed at length elsewhere (pp. 31–34), point to a pre-Cambrian age for the Wissahickon gneiss of the Doe Run and Avondale region. The Wissahickon mica gneiss is correlated with portions of the Carolina gneiss.

Name.—The name Wissahickon was given to this formation on account of its fine exposures along the banks of Wissahickon Creek, near Philadelphia.

CAMBRIAN.

CHICKIES FORMATION.

Distribution.—The Chickies formation, of which quartzite is the most conspicuous member, associated with gneissic and schistose bands, forms the steep ridge of the North Valley Hills, extending across the northwestern part of the Doe Run district (fig. 4) in a straight band of almost uniform width, whose general direction is parallel to the trend of Chester Valley. On the south the quartzite

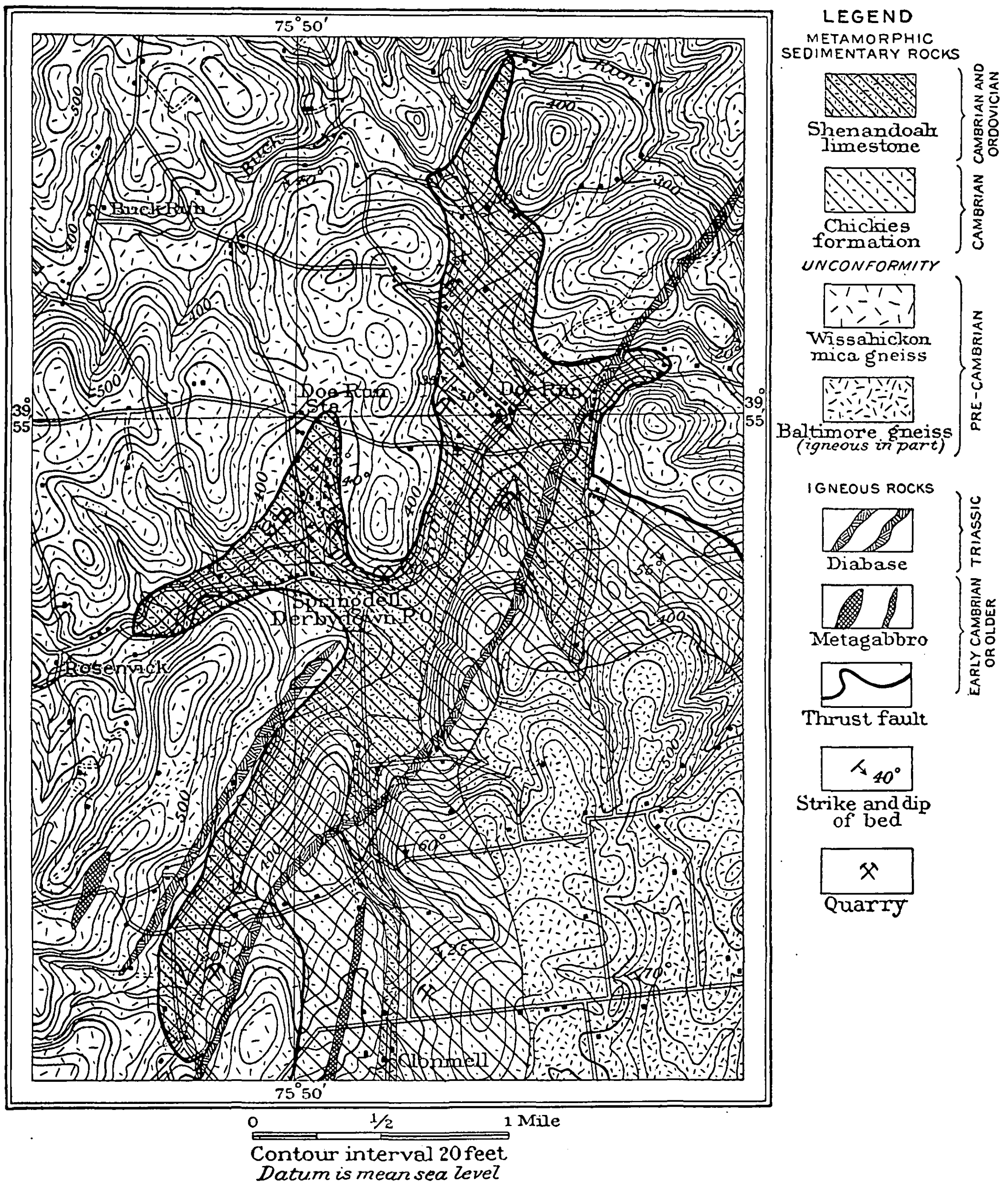


FIGURE 4.—Geologic map of Doe Run valley, Chester County, Pa.

passes conformably under the Shenandoah limestone of Chester Valley; on the north it overlies the Baltimore gneiss. The limestone and the quartzite together form the southern limb of an anticline whose core of pre-Cambrian gneiss is brought to the surface north of Coatesville.

In the neighborhood of Doe Run the quartzite comes to the surface as a band of varying thickness which overlies the northeastern, northern, western, and southern flanks of the Baltimore gneiss.

North of Avondale and Toughkenamon another area of the Chickies formation is bounded by limestone. The formation also forms a ridge north of Westgrove.

Field relations.—The hardness and chemical stability of the Chickies formation make its outcrop a prominent topographic feature. The rock is well exposed in several quarries in the North Valley Hills; on the road going southwest from London Grove, where two quarries are cut in the northern face of the hill; and in the quarries of the hill north of the State road from Avondale to Toughkenamon. The general strike of the formation is N. 60° E. and the dips are in all observed exposures to the southeast with an average inclination of 20°. At the contacts of quartzite and limestone the limestone appears to underlie the quartzite, a relation which is the result of overturned folding.

Lithologic character.—The Chickies formation is composed of quartzite, mica schist, and mica gneiss. The quartzite is a cream-white to gray fine-grained crystalline thin-bedded rock. Sericite is developed parallel to the bedding planes and causes the rock to split easily into flat slabs. The mica gneiss member of the formation is a gray fine-grained crystalline, slightly banded gneiss, whose constituents are quartz, biotite, and muscovite abundantly present and feldspar sparingly so.

With an increase in the amount of mica the rock becomes a mica schist, a pinkish or grayish-green rock in which small sparkling plates of mica produce a frosted effect. This Cambrian mica schist resembles the Wissahickon mica gneiss, but the mica in the schist is usually present in smaller flakes than it is in the gneiss, and the Cambrian rock, in distinction from the Wissahickon, has straight bedding planes. The two rocks are further distinguished by structural relations and by a characteristic aspect that is difficult to define. "Stretched" tourmaline—that is, broken and linearly displaced tourmaline—is found in all three members of the Chickies formation.

The quartzite of the North Valley Hills is a pure hard white compact fine-grained, heavily bedded rock, with abundant small flakes of glistening sericite developed along the bedding planes. In the neighborhood of Doe Run the Cambrian formation is represented by the quartzose and schistose members. Near Springdell it is represented by the mica gneiss. All these facies occur in the Chickies formation as exposed on the western and southern flanks of the Baltimore gneiss anticline. The Chickies northeast of Avondale and Westgrove is the mica gneiss facies, in which abundant mica is disseminated throughout the rock.

Microscopic study shows that the feldspar is largely microcline, but orthoclase, andesine, and bytownite are also present. Magnetite, zircon, pyrite, titanite, perofskite, and tourmaline are accessory constituents.

Analysis.—The analysis of a specimen of quartzite from the ridge south of Langhorne, Pa., is given below.[1] It shows high silica content and sufficient alumina and potassa to form muscovite and feldspar.

Analysis of quartzite of Chickies formation.

SiO_2	87. 87	Ignition	1. 20
Al_2O_3	6. 61	TiO_2	. 38
Fe_2O_3	2. 39	P_2O_5	. 06
MgO	Trace.	MnO	. 13
CaO	. 24		
Na_2O	. 19		100. 80
K_2O	1. 73		

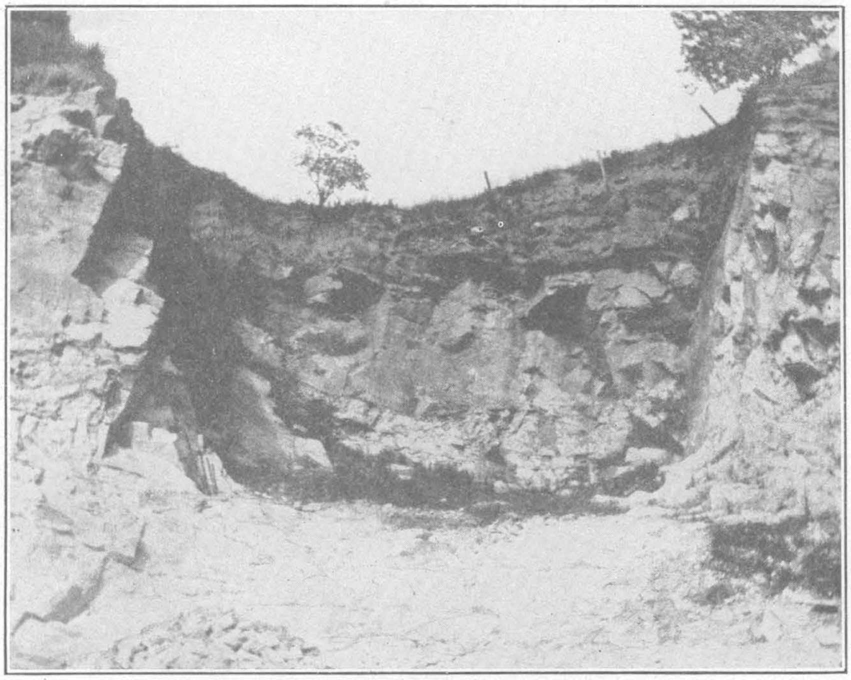
Thickness.—The close isoclinal character of the folding makes the determination of the thickness of this formation difficult. Its estimated thickness in Chester Valley is 1,300 feet,[2] but in the Doe Run district a thickness of 1,500 feet seems probable. The section exposed on the Doe Run road represents a deposit of about 1,000 feet. (See Pl. II, *B*.) Within the Avondale area (fig. 5) the thickness of the Chickies formation varies from 700 to 800 feet. The variability in thickness of the formation in the region south of Chester Valley is presumably due to original irregularity of deposition in the estuaries of the Cambrian sea.

Age and correlation.—The quartzite of the North Valley Hills forms a continuous band which extends from the western edge of Bucks County to the vicinity of Gap, in Lancaster County. Borings of *Scolithus linearis* have been found at several places in the quartzite of the North Valley Hills, which is in direct stratigraphic continuity with the quartzite near Coatesville. In 1896 Walcott[3] deter-

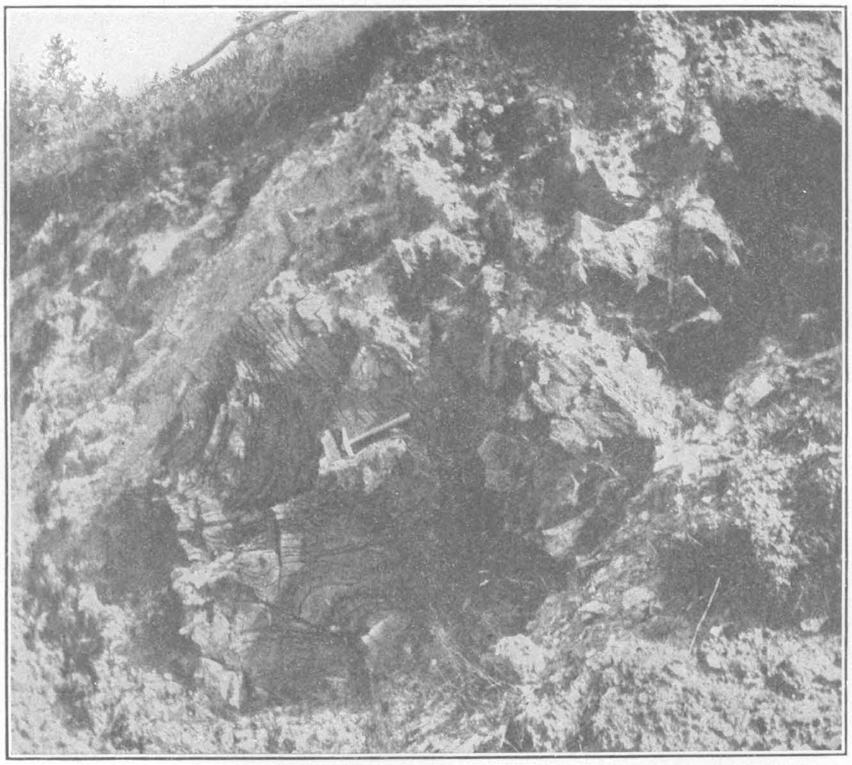
[1] Pennsylvania Rept. Second Geol. Survey C6, p. 117, 1881. Analysis by F. A. Genth, jr.

[2] Bascom, Florence, U. S. Geol. Survey Geol. Atlas, Philadelphia folio (No. 162), p. 4, 1909.

[3] Walcott, C. D., The Cambrian rocks of Pennsylvania: U. S. Geol. Survey Bull. 134, p. 17, 1896.



A. QUARRY IN SHENANDOAH LIMESTONE, 1½ MILES SOUTHEAST OF DOE RUN, CHESTER COUNTY, PA.



B. SECONDARY FOLDS ON LIMB OF ANTICLINE IN CHICKIES FORMATION ON DOE RUN ROAD, CHESTER COUNTY, PA.

mined the position of the Scolithus-bearing quartzite as underlying shales and calcareous sandstone which contain fragments of Olenellus. This determination establishes the age of the Scolithus-bearing rock as Lower Cambrian. The rock south of the North Valley Hills does

Name.—The name Chickies (formerly spelled Chikis) was first used to describe the rock exposed on Susquehanna River near Columbia, Lancaster County. Later the spelling was determined as Chickies by the United States Geographic Board.

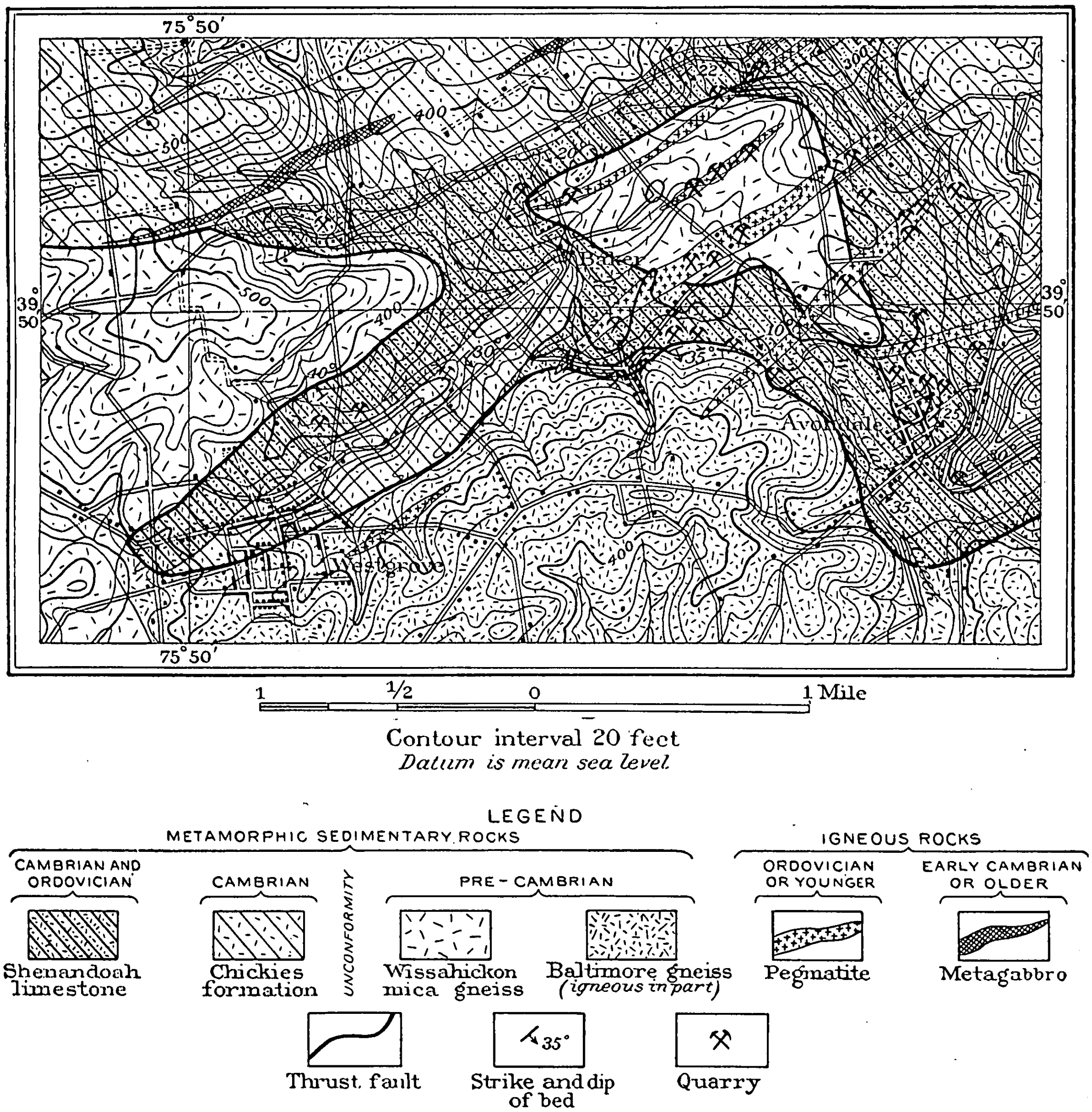


FIGURE 5.—Geologic map of Avondale Valley, Chester County, Pa.

not contain *Scolithus linearis*, but from its lithologic character and structural relations may be correlated with the Chickies quartzite of the North Valley Hills. The formation has been correlated with the Cheshire ("Poughquag") quartzite of New York, the Hardyston quartzite of New Jersey, and the Setters quartzite of Maryland.

CAMBRIAN AND ORDOVICIAN.

SHENANDOAH LIMESTONE.

Distribution and field relations.—In the northern part of the Doe Run district (see Pl. I, p. 10) the outcrop of Shenandoah limestone corresponds perfectly to the floor of Chester Valley, forming a narrow belt, which varies in width from one-fourth to three-fourths of a mile. On the north side of the valley the limestone overlies the quartzite, which is exposed on the southern limb of an anticline. Toward the south the limestone passes conformably under the Octoraro schist of the South Valley Hills.

In the central and southern parts of the Doe Run district limestone occurs in four distinct areas of irregular conformation. The largest area extends from Buck Run almost due south to Doe Run village, where the outcrop is pierced by an anticlinal hill of resistant quartzite. From Doe Run southwest to Green Lawn there is a continuous outcrop of limestone, and from Springdell directly south limestone joining the western flank of the quartzite occurs in a long valley that extends to the southern edge of the Doe Run district.

On the northern and northeastern boundary of the quartzite the limestone occurs in two small but distinct outcrops at Guest's and Logan's quarries. (See Pl. II, *A*.) The fourth occurrence is a narrow and irregular outcrop along a tributary of Brandywine Creek, about 2 miles northeast of Logan's quarry and 1 mile north of Upland.

Except where it borders the quartzite the limestone of these areas is surrounded by the Wissahickon mica gneiss, thereby producing a radial and finger-like arrangement of the surface outcrops which is particularly striking. (See fig. 4.)

In the Avondale district (see fig. 5) the limestone occupies the valley of White Clay Creek about Avondale and to the north, and the valley of West Branch of White Clay Creek and its tributaries near Landenberg. The areas are not more than half a mile wide and are very irregular. The northern area extends southwestward for about 5 miles from the center of the eastern border of the Coatesville quadrangle; then it turns south and curves about a hill of mica gneiss which lies north of Westgrove; from that point it extends southward through Baker and southeastward to Avondale, where it connects with two belts of the formation—one from the east along Trout Run and the other from the north. (See fig. 5.) About a mile south of Landenberg there is a small area of limestone extending southwestward along Broad Run and across White Clay Creek almost to West Branch. It is not more than a mile wide anywhere and does not appear at the surface except at Nevin's quarries.

As there are no natural outcrops of the limestone, its extent is best determined by the soil it makes—a red clay such as is formed by the weathering of a magnesian lime rock. It is exposed for the most part in abandoned quarries which are partly filled with water; the rock forming the walls may be fresh or partly disintegrated into calcareous sand or almost entirely covered by a talus of soil. In the region of Baker and Avondale there are large quarries which are now being operated in this rock and which furnish valuable marble and building stone.

The strike of the formation ranges between N. 60° E. and N. 70° E. The direction of dip is generally southeast, the only prominent exception being a northwest dip found in a small quarry just north of Westgrove. The angle of dip is low, varying from 20° to 25°.

Lithologic character.—Three varieties of the Shenandoah limestone are recognizable in the Doe Run and Avondale region. One occurs in Chester Valley, where the fresh rock is a massive, highly crystalline blue magnesian limestone, which breaks readily along three joint planes. Few accessory minerals are found in this massive variety. The upper member of the formation in this area is a highly micaceous and thinly bedded schistose rock, in which quartz and mica are so abundant that the rock may be called a calcareous schist. This member grades into the overlying Octoraro schist.

The third variety occurs in the central belt of limestone, where it is well exposed in Guest's and Logan's quarries, and in the limestone of the Avondale district. Where pure the fresh rock is a medium-grained, highly crystalline lustrous white saccharoidal marble, characterized by the abundant development of various accessory minerals. Phlogopite, in glistening amber-brown scales, is in some places so plentiful that, on planes parallel to the bedding, the rock may appear to be composed almost entirely of mica. Where the phlogopite occurs in smaller flakes it gives the rock a variegated appearance, which has won for it the name "bastard granite." Biotite, muscovite, tourmaline in large black crystals, magnetite, apatite, and pyrite are common accessory minerals.

Evidences of pressure seen in the thin section are twinning of the calcite crystals, granulation, and undulatory extinction of the quartz, which occurs in interlocking areas forming a mosaic with the calcite. The dolomite of Chester Valley is finer grained than the limestone of the southern area, which in Guest's quarry is almost pure calcite.

Analyses.—Some analyses of the limestone are given below:

Analyses of Shenandoah limestone.

	1	2	3	4
$CaCO_3$	54.750	40.27	54.071	57.125
$MgCO_3$	44.204	31.24	43.309	12.498
SiO_2	....	24.23	....	1.235
Fe_2O_3	} .517	1.06	} .621	3.770
Al_2O_3		1.12		
MgO	....	.11	....	....
CaO	....	.55	....	....
H_2O	....	....	....	} 25.372
CO_2	....	....	....	
S	.011	....	.013	....
P	.010	....	.003	....
Alkalies	....	1.42	....	....
Insoluble	.436	....	1.950	....
	99.928	100.00	99.959	100.000

1. Haldeman South quarry, near Chickies. Best blue limestone, fine grained, hard. Analyst, A. S. McCreath, Pennsylvania Second Geol. Survey Rept. CC, page 271, 1874.
2. West Conshohocken, Montgomery County, Pa. Analyst, F. A. Genth, jr., Pennsylvania Second Geol. Survey Rept. C6, page 126, 1881.
3. Benjamin Swayne quarry, 2 miles north of Avondale. Analyst, F. A. Genth, jr., idem, page 127.
4. Pennsylvania Marble & Granite Co.'s quarry, Baker. Analysts, Booth, Garrett & Blair, Philadelphia.

Thickness.—In the Avondale district the thickness of the limestone, which does not exceed 1,000 feet, represents only part of the original thickness; the remainder has been removed by erosion. In Chester Valley the formation is probably not over 1,500 feet thick.

Age and correlation.—In the central part of the region, at Guest's quarry, and in the northern part, in Chester Valley, the limestone conformably overlies the Chickies formation. On account of the highly metamorphosed character of the rock, fossils are rare in the Shenandoah limestone and none have been found in the Doe Run and Avondale region, but at Henderson station, Montgomery County, Pa., fossils of Ordovician age have been found in the limestone of Chester Valley.[1]

That the limestone of the Doe Run and Avondale region is to be correlated with the Cambrian and Ordovician Shenandoah limestone of Montgomery and Delaware counties is proved by the stratigraphic continuity of the limestone in Chester Valley, by marked lithologic resemblance between the limestone of the Doe Run and Avondale region and the rock in Chester Valley, and by the position of the limestone south of Chester Valley in approximately the same line of strike as the narrow belt of Shenandoah limestone in Cream Valley near Conshohocken, Pa.

Name.—The name Shenandoah was adopted by Darton [2] in 1892 to designate the limestone formation of Cambrian and Ordovician age which occurs in the Appalachian region of Virginia. Subsequently the United States Geological Survey accepted the name because of its priority and applied it to the "Chester Valley" limestone and to the outcrops southeast of Chester Valley which had been correlated with the Shenandoah.

ORDOVICIAN.

OCTORARO SCHIST.

Distribution and field relations.—The north face of the South Valley Hills forms the northern boundary of the outcrop of the Octoraro schist; the southern boundary is a line passing about half a mile north of the village of Timicula, through Ercildoun, a quarter of a mile west of Youngsburg, north to Modena, where it runs in a southeasterly direction to the eastern boundary of the Coatesville quadrangle.

The schist conformably overlies the Shenandoah limestone on the north, grading imperceptibly into the limestone through a calcareous lower member; on the south it adjoins the Wissahickon mica gneiss, the line of contact representing a fault which extends across the country in a roughly northeast direction. The average strike of the formation is N. 65° E. and the dips are about 60° SE.

[1] Bascom, Florence, U. S. Geol. Survey Geol. Atlas, Philadelphia folio (No. 162), p. 5, 1909.

[2] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Staunton folio (No. 14), 1894.

In topographic features the country underlain by the Octoraro schist is very similar to that formed by the erosion of the Wissahickon mica gneiss. The schist, like the gneiss, yields readily to the mechanical processes of weathering and forms a deep micaceous soil, which differs from the gneiss soil in that it does not contain individual flakes of mica, but rather small fragments of the rock that have not been disintegrated into the individual constituents.

The soil produced by the disintegration of the schist is dull and sandy, nongarnetiferous, and full of green, shiny fragments that have a soapy feel, but the gneiss soil is glistening and sparkling with large flakes of mica, abundantly garnetiferous, and less likely to be red. Another marked difference in the two formations is the method of disintegration. The Octoraro schist does not have the three well-marked joint planes which cause the Wissahickon gneiss to break readily into parallelepipeds; but, having an easy cleavage along the planes of schistosity, it splits into thin laminated fragments.

Lithologic character.—The Octoraro schist may be described as a quartz-muscovite schist or a quartz-chlorite schist, in which the mineral constituents are so minute that on the cleavage planes no one mineral is distinguishable. The fresh rock is light silvery gray and very schistose in character and is composed of quartz and mica or chlorite. The quartz, which is visible only on the edge transverse to the cleavage plane, occurs in lenses completely wrapped around by the micaceous layers; on cleavage planes mica alone is visible in microscopic flakes that are indistinguishable in the hand specimen. These micaceous constituents form a surface with a smooth "feel," which has been described as "soapy." The color varies from gray in the fresh rock to green or yellow in the weathered rock.

In the thin section the schistose character of the rock is very apparent. Small grains of quartz, showing hornstone texture, form continuous bands throughout the rock or occur in lenses enveloped by twisted fibrous muscovite or muscovite and chlorite; muscovite may be present in fine blades and chlorite may be almost entirely absent, or muscovite and chloritized biotite may occur together, associated with secondary quartz, hematite, and magnetite. The accessory minerals are pyrite, magnetite, perofskite, titanite, rutile, and apatite.

The sedimentary origin of the schist is shown both in its field relations and in its composition. It is the upper member of a conformable series of sandstone, limestone, and shale, and has the restricted mineral content and hornstone texture of a sedimentary deposit that has undergone metamorphism.

Analysis.—The composition of the schist is shown by the following analysis:

Analysis of Octoraro schist.

SiO_2	39.35	Ignition	6.05
Al_2O_3	31.92	TiO_2	1.20
Fe_2O_3	2.19	P_2O_5	.49
FeO	9.00	NiO (trace of cobalt)	.06
MgO (deficient)	3.08		
Na_2O (deficient)	1.98		100.58
K_2O	5.26		

Mica schist, 1,222 feet from Bird in Hand Tavern, on road from Gulf Mills to Bryn Mawr, Montgomery County, Pa. Pennsylvania Second Geol. Survey Rept. C6, p. 133, 1881.

The small content of the alkalies and alkaline earths relative to the silica and alumina, the absence of lime, and the preponderance of potash over soda in the analysis point to a sedimentary origin of the formation in which the more readily soluble substances, such as lime, soda, and the alkalies, have been removed in solution.

Thickness.—In the syncline of the South Valley Hills the thickness of the Octoraro schist seems to be about 2,000 feet.

Age and correlation.—The Octoraro schist conformably overlies the Shenandoah limestone, grading down into the limestone through a calcareous schist, and is therefore of Ordovician age. It has been correlated with the Berkshire and Hoosac schists of New England.

Name.—The name Octoraro has been given to the schist because it is particularly well exposed along the banks of Octoraro Creek, between Lancaster and Chester counties.

IGNEOUS ROCKS.

EARLY CAMBRIAN OR OLDER.

METAGABBRO.

Distribution.—About a mile northwest of Coatesville the Baltimore gneiss is penetrated by two intrusive gabbro masses. Only the southern extremity of one intrusion is visible in the region under discussion; the other mass extends eastward from the western boundary of the region mapped (Pl. I) to Valley station, on Rock Run. A small dike occurs on the east side of Rock Run.

In the southern part of the Doe Run district and throughout the Avondale district metagabbro occurs in narrow dikes in the Baltimore and Wissahickon gneisses and the Chickies formation. The outcrops of the dikes north of Avondale range in width from a few feet to half a mile. About Wickerton, New Garden, and Landenberg the dikes are of considerable size. South of Landenberg a series of narrow dikes, roughly parallel in direction, may be traced for 5 or 6 miles southwestward to the southern edge of the Coatesville quadrangle.

Field relations.—The dikes of hornblende gneiss cut the country rock with varying strike, and are in places weathered into a soft dark-green rock in which hornblende may still be distinguished.

Lithologic character.—The rock of the two areas northwest of Coatesville is a holocrystalline, granular, or only slightly gneissic medium to fine grained gabbro. The only constituents visible to the naked eye are plagioclase, a dark-green pyroxene, and brown hornblende in slender crystals. The metagabbro is a fine-grained dark-colored rock, for the most part green to greenish black, with leucocratic constituents mottling it. Lustrous hornblende, the most abundant and conspicuous constituent, has a parallel arrangement and thus gives the rock a banded appearance. The feldspar occurs in minute grains of a dull chalky aspect. In thin section it is found that this aspect of the feldspar is due to saussuritization, which obscures the original character of the feldspar. The character of the extinction angle indicates that the feldspar is labradorite-bytownite. Hornblende has been formed by uralitization—that is, by the alteration of the original augite into hornblende. A core of augite is present in the interior of some of the hornblende crystals, where its pale-green to colorless character, its high index of refraction, and its occasional basal sections with rectangular cleavage separate it sharply and conspicuously from the surrounding hornblende. The gneiss, with its basic feldspar, uralitized augite, and accessory zircon, has the constitution of a quartz-augite gabbro. It is at present a metagabbro or, because of its secondary banding, a hornblende gneiss.

Analysis.—The following analysis[1] represents a dike of similar metagabbro which occurs a mile north of Bryn Mawr station:

Analysis of metagabbro.

SiO_2	48.68	ZrO_2	Not estimated.
Al_2O_3	14.39	P_2O_5	0.29
Fe_2O_3	4.00	Cl	Not estimated.
FeO	10.09	S	Trace.
MgO	6.32	Cr_2O_3	None.
CaO	9.23	NiO	Trace.
Na_2O	2.31	MnO	.22
K_2O	.47	BaO	Faint trace.
H_2O+	2.03	SrO	None.
H_2O-	.46	Li_2O	Trace.
CO_2	None.		
TiO_2	1.69		100.18

The analysis gives the following norm:

Norm of metagabbro.

Quartz	2.82	Magnetite	5.80
Orthoclase	2.78	Ilmenite	3.19
Albite	19.39	Apatite	.67
Anorthite	27.52	Water	2.49
Diopside	13.67		
Hypersthene	21.78		100.11

The rock falls in Class III, order 5, rang 4, and subrang 3 and is a hornblende grano-auvergnose; it is perfelic, docalcic, and presodic. The compound prefix is given because hornblende is the only abnormative mineral and because the texture of the rock is hypautomorphic granular.

Origin.—There can be no question of the igneous origin of the metagabbro, for the field relations, mineral constituents, and chemical composition concur in pointing to such an origin. Since the intrusion and consolidation of the gabbro pressure has converted the augite into hornblende and has produced a rock cleavage parallel to the prevailing southeastward dip of the cleavage of the region.

Age.—The gabbro has nowhere been found intruded into recognized Paleozoic sediments, but large masses of gabbro have been found in pre-Cambrian rocks throughout the eastern Piedmont belt, and it can therefore be regarded as belonging to the period of pre-Cambrian igneous activity. The presence of a

[1] Geol. Soc. America Bull., vol. 16, p. 319, 1905. Analyst, W. F. Hillebrand, U. S. Geol. Survey.

dike of hornblende gabbro in the Chickies formation makes it seem likely that a portion of the original magma which furnished the material for the pre-Cambrian intrusions may have been injected into fissures either during the period of Lower Cambrian deposition or at some later time.

PRE-SILURIAN OR YOUNGER.

SERPENTINE.

Distribution and field relations.—The occurrence of serpentine in the Doe Run district is restricted to three small lenticular areas, which range in length from a quarter of a mile to half a mile, and are about one-eighth of a mile in width. Two of these areas are situated near Laurel, on the West Branch of Brandywine Creek, and the third is about a mile southeast of Goosetown. The outcrops are nowhere prominent, being confined to cuttings in the hillsides near Laurel and to a few scattered bowlders in the fields near Goosetown. Owing to the small extent of the areas it is impossible to recognize the presence of serpentine by its characteristic thin soil and stunted vegetation. The lenticular shape of the areas and the character of the rock itself are evidences of its igneous origin. The Laurel outcrops are within the confines of the Wissahickon mica gneiss; the Goosetown outcrop is partly surrounded by the Ordovician schist. In the Avondale district there is a small outcrop of serpentine on the Toughkenamon and London Grove road $1\frac{1}{2}$ miles north of Toughkenamon. The rock, which is exposed in a road cut, is only a few feet in width and does not reappear along the strike. The exposure is surrounded by Cambrian gneiss belonging to the Chickies formation.

Lithologic character.—The serpentine in the region of Laurel is a soft green, extremely talcose schist, almost approaching a soapstone; in the neighborhood of Goosetown it is a massive green serpentine. The thin section of the Goosetown rock shows that it is composed mainly of serpentine; other alteration products are talc, calcite, and iron oxides. The rock has been so completely altered to serpentine that the original character is difficult to determine, but a few small grains of residual olivine remain, showing that the rock was derived from a peridotite. The rock north of Toughkenamon is almost a tremolite schist; it is green in color, fibrous, and soft.

Age.—Throughout the eastern Piedmont district of Pennsylvania there are many serpentine dikes whose occurrence, except in the isolated areas near Goosetown and Toughkenamon, is restricted to pre-Cambrian rocks. In many places in the immediate vicinity of Philadelphia and around Chester and West Chester serpentine is intruded into the pre-Cambrian gneisses, but it nowhere occurs in a formation later than the Wissahickon gneiss.

Owing to the common occurrence of serpentine in pre-Cambrian material and to its almost total absence from Paleozoic material, it seems possible that the serpentine near Goosetown, which is a metamorphosed peridotite, belongs to the pre-Cambrian period of igneous activity and that it was carried in a small patch of igneous material along with the overthrust Wissahickon gneiss over the surface of the schist and left by subsequent erosion. The area appears to be partly surrounded by the Wissahickon mica gneiss, but the cultivation of the farm land in which the serpentine occurs makes it difficult to map the border accurately. The irregular character of the boundary between the Wissahickon gneiss, serpentine, and Octoraro schist is such as would be expected to result from the partial removal by erosion of the overlying rock. It is possible that the serpentine of the area north of Toughkenamon is a remnant of overthrust pre-Cambrian material left by erosion, or that it is a land area which remained an island during the whole or part of Cambrian and Ordovician time.

In Syracuse, N. Y., serpentine occurs in the Salina formation, of Silurian age, formerly called "Onondaga salt group," and Williams [1] has called attention to the fact that this serpentine bears a strong resemblance to the Carboniferous peridotites of Kentucky described by Diller.[2] The occurrence of post-Carboniferous serpentines in the Appalachian province suggests that the serpentine here discussed may possibly be of later age than

[1] Williams, G. H., On the serpentine (peridotite) occurring in the Onondaga salt group at Syracuse, N. Y.: Am. Jour. Sci., 3d ser., vol. 34, p. 137, 1887.

[2] Diller, J. S., Peridotite of Elliott County, Ky.: U. S. Geol. Survey Bull. 38, 1887.

Ordovician and therefore intrusive in the Octoraro schist of the Doe Run district and in the Cambrian gneiss of the Avondale district. In view, however, of the absence of conclusive evidence showing the Paleozoic or post-Paleozoic age of the serpentine in the Goosetown and Toughkenamon areas, and in view of the preponderance of igneous material in the pre-Cambrian rocks, it seems impossible to determine the age of the serpentine without further discovery of its occurrence in Paleozoic material.

PEGMATITE.

Distribution and field relations.—Pegmatite occurs at eight places in the Doe Run district. Four dikes extend across the country in the neighborhood of Coatesville, striking northeast. Three of these dikes occur northeast of the town, showing themselves in bowlders scattered through the fields; the fourth, which lies directly east of Coatesville, is a seam of kaolin within the confines of the limestone. Of the four pegmatite localities in the southern part of the Doe Run district, three lie in a continuous line northeast of Upland. There are only two direct outcrops of the rock in the Doe Run district. One is an old spar pit on the Sharpless farm at Upland; the other, in direct line of strike with the first, is a dike of quartz-feldspar rock in Logan's limestone quarry.

The Avondale district contains many pegmatite dikes. With the exception of an isolated outcrop north of Chatham, the areas of pegmatite north of Avondale may be grouped into five dikes, the largest of which is an eighth of a mile wide. The northernmost dike appears a mile south of London Grove, whence it may be traced to Baker; the other four lie to the southeast, each separated from the next by about half a mile and the southernmost cropping out just north of Avondale. Between Avondale and Landenberg the pegmatite dikes are scattered and small, but south of Landenberg, in the neighborhood of the limestone, four dikes cut the metagabbro, the Baltimore gneiss, and the Shenandoah limestone. Many other dikes too small to be mapped cut the country rock of that region.

Lithologic character.—The pegmatite is a coarse-grained white to gray rock composed of quartz, light-gray or pink feldspar, and abundant muscovite in large plates. The feldspar when fresh has lustrous surfaces but when weathered is abundantly coated with a yellow iron oxide stain. The feldspar may be orthoclase with Carlsbad twinning or, more rarely, with twinning according to the Baveno law; or microcline with the gridiron texture; or oligoclase; or microperthite. The most prominent of the long list of accessory minerals associated with the pegmatite are iron pyrites, tourmaline, and garnet.

The absence of banding, the coarse crystallization, and the diversity in texture and mineral composition are all evidences that the pegmatite is not a normal plutonic rock which has undergone the pressure to which the other rocks of the region have been subjected. On the other hand, the trend of the dikes, discordant to the strike of the country rock, is unlike that of the veins of the region.

Origin.—The pegmatite dikes of this region represent the most highly differentiated phase or end product of an igneous magma. They show more igneous than aqueous characteristics and may be explained as the result of slow crystallization of an igneous magma saturated with water. They are the youngest pre-Triassic igneous rocks of the region and represent the expiration of the igneous activity which began in pre-Cambrian time and which is represented in the Coatesville region by the metagabbro and in the Philadelphia region by the porphyritic granite, gabbro, and ultrabasic peridotite and pyroxenite.

The points of difference between pegmatites and plutonic rocks have already been mentioned. The pegmatite is coarse and irregular in texture and has not the uniform constitution of a granite. It is like a granite in its order of crystallization and like a dike in its occurrence in the field.

Age.—The pegmatite has not been found in rocks younger than the Shenandoah limestone. Its intrusion was subsequent to the pressure that produced the thrust fault of the Wissahickon mica gneiss, and its age may be pre-Silurian or younger.

TRIASSIC.

DIABASE.

Distribution and field relations.—Diabase occurs in five dikes in the Doe Run and Avondale region. One line runs through the Doe

Run district in a southwesterly direction from a locality about 1½ miles southeast of Goosetown to the neighborhood of Green Lawn, and the great trap dike of Downingtown, northeast of Coatesville, may be regarded as a continuation of it. West of this long dike a shorter one extends from Springdell to Green Lawn. On each side of a line drawn from Woodville to Chatham a dike of diabase may be traced southwestward for about 4 miles. A fifth dike near Woodville extends for about 1½ miles. Except for a few ledges, the existence of the diabase is indicated only by a trail of bowlders across the country underlain by the rock. It strikes N. 45° E., and the width of the dikes where exposures exist is about 20 feet.

Lithologic character.—The Downingtown dike is a rather coarse grained diabase, composed of crystals of plagioclase and green pyroxene. The rock of the dikes near Woodville is typical fine-grained diabase, in which the only mineral constituent recognizable with the naked eye is pale-green feldspar sparkling in a dark greenish-gray groundmass. Microscopic study shows that the feldspar is labradorite-bytownite and occurs in automorphic lath-shaped crystals so arranged as to produce the ophitic texture characteristic of diabase. The microscope also shows pyroxene, which is pale-green augite and unusually fresh and which occurs as xenomorphic individuals within the network of feldspar. The accessory minerals are magnetite, epidote, quartz, biotite, apatite, and chlorite, with secondary ilmenite. The rock has a conchoidal fracture and when exposed to the atmosphere for some time weathers into spheroidal bowlders with a yellow exterior and a greenish-gray interior.

Analysis.—The following analysis represents a specimen of the Conshohocken dike in West Conshohocken, Montgomery County, Pa.:[1]

Analysis of diabase from Conshohocken dike.

SiO_2	51.36	K_2O	1.46
Al_2O_3	17.38	Loss	2.15
Fe_2O_3	6.57	TiO_2	1.63
FeO	3.85	PO_4	.13
MgO	3.42	Li_2O	Trace.
CaO	10.19		
Na_2O	2.19		100.53

[1] Pennsylvania Second Geol. Survey Rept. C3, p. 275, 1880; Rept. C6, p. 134, 1881. Analysis by F. A. Genth, jr.

This analysis gives the following norm:

Norm of diabase from Conshohocken dike.

Quartz	10.14	Ilmenite	3.04
Orthoclase	8.90	Magnetite	7.66
Albite	18.34	Hematite	1.28
Anorthite	33.08	Water	2.15
Enstatite	8.60		
Wollastonite	6.96		100.49
Apatite	.34		

This diabase is a dosalane which is docalcic and presodic—in other words, the salic constituents are dominant over the femic and the lime over the alkalies. Of the alkalies soda preponderates. The rock is an augite ophitibandose.

Age.—In its freshness, mineral constitution, and microtexture the rock found in the Doe Run and Avondale region resembles the Triassic diabase. It is in line of strike with the Downingtown dike, which has been traced northeast into Triassic formations and which extends intermittently southwest as far as Maryland, crossing the Phoenixville and West Chester quadrangles and appearing in the Coatesville quadrangle as here described.

STRUCTURAL GEOLOGY.

STRUCTURE OF THE PIEDMONT PLATEAU.

The crystalline rocks of the Piedmont region comprise closely folded and faulted Paleozoic and pre-Paleozoic rocks, partly concealed by a cover of gently folded, unmetamorphosed Mesozoic shales and sandstones, which dip gently northwest and are broken by a series of normal and reverse faults with a southeast hade. In strong contrast to the simple structure of the shales and sandstones, the belt of crystalline rocks that lies southeast of the Mesozoic cover presents a succession of close unsymmetrical folds, sharply overturned toward the northwest and dislocated by thrust faults with a prevalent southeast hade. The folding appears to be isoclinal, because the limbs of the folds are compressed closely and the folds are usually overturned. They strike in a general northeasterly direction, but the axis of the major folds is usually inclined more or less gently, and this pitching of the axis shows that there has been gentle folding at right angles to the major folding. The period of stress that began in

Archean and Paleozoic time was marked by the gradual accumulation in the earth's crust of compressive forces which sought relief in two directions, thereby producing two systems of folding—one, compressed and overturned major folds; the other, gentle and open minor folds. This difference in the intensity of folding may be due to the fact that the pressure originating along the minor axis was less than that along the major axis; or it may be due to the greater resistance of the strata along the minor axis, or to the combination of these two causes. The compressed folds lie along a northeast axis, producing a succession of overthrusts that have been gradually developed as the result of a major force working from a southeast direction. A thick limestone formation was the controlling factor in the folding of the Paleozoic sediments, and the more deeply the layer was buried the more readily it yielded to pressure.

In the sharp overthrusts of the major folds, warping of the earth's surface produced a weakness which, by concentration along the axis of overthrust, has caused a repeated sliding of the earth's crust. In the zone of combined fracture and flowage, by means of lateral pressure, combined with slight overloading, the elasticity of the material is exceeded so that the rock is fractured along the limbs of the folds, with movement along both sides of the rupture. Such faults have a gentle hade in a southeasterly direction and along them the deeply buried Archean rocks were pushed up until they overlay the younger Paleozoic sediments. The faults strike in a general northeast direction, and their linear extent is extremely variable. The faults in the Triassic beds are normal, with a hade of 75° SE. to 90° and with slight displacement.

Cleavage, fissility, and jointing are also characteristic features of the crystalline schists of the Piedmont Plateau. Jointing is caused by the yielding of the rock along shearing planes and is usually found in three directions nearly normal to one another; it is supplemented by the plane of cleavage and fissility, which is in many places almost normal to the joint planes. Fissility is a structure resulting from heat, pressure, and metamorphism, by virtue of which rocks are separated into parallel laminæ. In the gneisses and schists rearrangement and flattening of the old minerals and a production of new minerals have caused an orientation of the mineral particles with their longer axes parallel. The parallel laminæ in crystalline schists are usually coincident with the bedding planes, differing from them only where the sediments are much plicated and the plane of fissility does not follow the close crumpling of the beds.

The yielding of the rock along shearing planes which produces jointing, cleavage, and fissility is, like folding, caused by lateral compression, owing to a tangential thrust from the direction of the Atlantic Ocean segment which continued during a long period of time and which acted most strongly in a direction at right angles to the strike of the major folds. At the same time vertical movements, bringing the beds to their present position, probably aided the work of horizontal compression, which is operative only at great depths in the zone of flowage and fracture. The two components of the force are lateral and vertical thrust. When open upright folds have passed by means of lateral thrust into closed and compressed folds, the vertical thrust tends increasingly to overturn them. The uniformity of the southeast dip of the formations shows that the major force was from that direction; the minor folding, normal to the major, resulted from suboceanic spread from the direction of the Gulf of Mexico. Tangential thrust began in pre-Paleozoic time and continued throughout the Paleozoic era, culminating at the close of the Carboniferous period. The belt of crystalline rocks which lies on the northwestern border of the Triassic cover presents the structural features described above, modified to some extent by its greater distance from the position of initial stress. In the southeastern belt an anticlinal arch brings to the surface the pre-Cambrian gneiss as the core of a great major fold. This arch, passing under the Triassic shales, is to some extent obscured by them but becomes plainly apparent along the northwestern boundary of the eastern belt of metamorphosed crystalline rocks. Farther southeast it passes into a synclinal trough of Ordovician material, of which the northwest limb forms Chester Valley and the southeast limb underlies a faulted cover of Wissahickon mica gneiss. A great anticline of pre-Cambrian gneiss follows the syncline and is succeeded by several folds which finally disappear under the

Cretaceous sediments of the Coastal Plain, on the southeast border of the Piedmont Plateau. The structure of this pre-Cambrian anticline is much obscured by many intrusions of igneous material, and in Maryland the anticline itself is broken up by igneous material.

STRUCTURE OF THE DOE RUN AND AVONDALE REGION.

FOLDS.

In the major folds of the Doe Run and Avondale region are represented the three great anticlines and the synclines described above. In the northwest corner of the region the Baltimore gneiss forms the core of the North Chester Valley anticline, which is flanked on the southeast limb by Cambrian quartzite, succeeded by the Cambrian and Ordovician Shenandoah limestone. Farther southeast, on the South Valley Hills, the Ordovician Octoraro schist comes to the surface in a wide, shallow syncline terminated by a long thrust fault, which has brought the Wissahickon mica gneiss into direct contact with the Ordovician schist. The peculiar course of this fault plane is treated in detail on page 27.

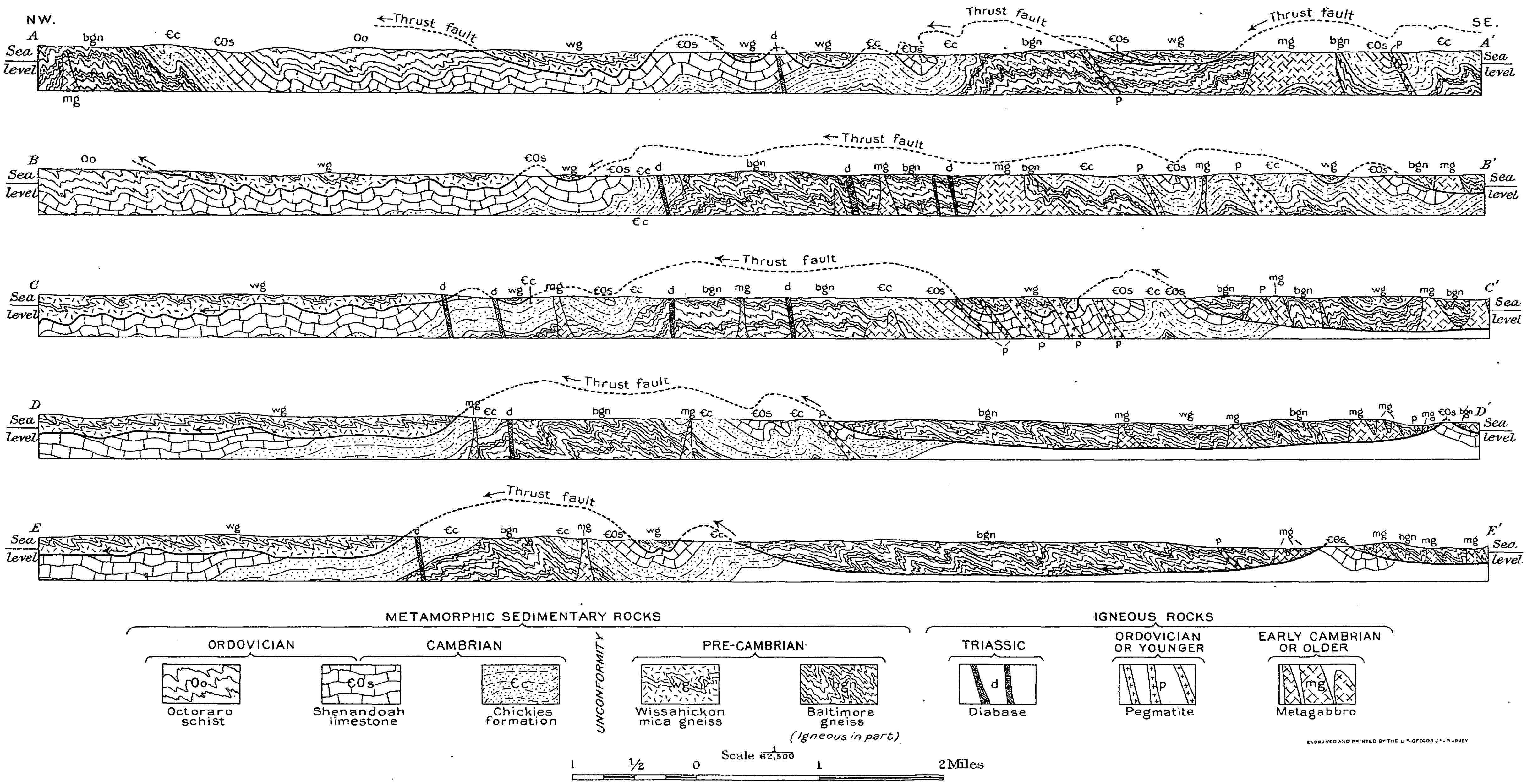
The rocks underlying the overthrust gneiss form a shallow synclinorium, here called the Modena-Chester Valley synclinorium. On the southeast limb of the synclinorium the underlying limestone comes to the surface in the crests of secondary anticlines, where stream erosion cutting through the overthrust cover of mica gneiss has established anticlinal valleys in the limestone.

An overturned syncline of quartzite and limestone separates the Wissahickon gneiss from the southern dome of the Baltimore gneiss, in which the rock forms a steep anticline overturned to the northwest. Southeast of this anticline, here known as the West Marlboro anticline, a synclinal wedge of limestone has been faulted upon the Baltimore gneiss along a fault plane having a very gentle southeast hade; the fault plane is split and the overthrust Wissahickon gneiss almost completely covers the syncline, leaving only a small remnant of limestone exposed. These structural features are shown in Plate III, section A–A′, which is drawn along a line normal to the average strike of the formations. The secondary and tertiary anticlines and synclines that compose the great folds are the controlling factors in the areal distribution of the formations. The Shenandoah limestone occupies, for the most part, synclines and it represents the troughs of folds remaining after the erosion of the rest of the formation, a relation of the limestone to the adjoining formations which is illustrated in Plate III.

South of Avondale the Baltimore gneiss is closely folded into small anticlines and synclines whose character is indicated by the prevailing southeasterly dips. South of Landenberg is an area of limestone which exhibits similar structure, the southeastern limb of a syncline cut off by an overthrust from the southeast.

This structure, which is illustrated by the sections, conforms to that prevailing in the southeastern part of the Piedmont region. The only striking divergence occurs in the limestone which extends from Baker southwestward and lies north of the Westgrove area of quartzite, where there is a normal upright syncline. The primary folds may be traced along the strike to the northeast and southwest. The Cabin John and Buck Ridge anticline extends from Maryland to New Jersey and throughout its length is bounded by synclines; the northern syncline passes into the anticline of the North Valley Hills, and the southern syncline extends southwestward until it is overlain by younger deposits of the Coastal Plain or obscured by pre-Cambrian igneous rocks.

The major folds, however, do not explain the pinching out of the Baltimore gneiss, the Chickies formation, and the Shenandoah limestone parallel to the strike, while to the northeast and southwest there is a uniform exposure of the Wissahickon gneiss. The explanation of the lack of formational continuity must be sought in the minor folding, which is rather pronounced in character. The anticline of pre-Cambrian gneiss represents a dome whose northeast and southwest flanks slope away in gentle minor synclines. A little farther northwest the same minor folding is apparent, but the axis is shorter. The northern finger-like limestone areas, from Springdell to Doe Run station and from Doe Run post office north to Buck Run, represent the crests of small minor anticlines. These anticlines pinch out toward the north, and the small minor syncline of Wissahickon mica gneiss which separates the lime-



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STRUCTURE SECTIONS OF DOE RUN AND AVONDALE REGION, CHESTER COUNTY, PA.

For lines of sections see geologic map (Plate I).

stone anticlines also dies away to the northwest, so that the undulation of the minor folding becomes scarcely perceptible.

FAULTS.

The rocks of this region are cut by a long thrust fault. In the northern part of the region the syncline in the Ordovician schist has been partly covered by this thrust fault, which, extending across the entire region, brings the Wissahickon mica gneiss over formations of several ages and into contact with the schist. The contact plane of the pre-Cambrian mica gneiss with formations of different age is everywhere the plane of the overthrust.

It is impossible to determine the exact extent of the Doe Run overthrust, but it is probable that the mica gneiss was carried over the surface of younger formations for more than 15 miles from the source of the fault. The original location of the Wissahickon has been obscured by the pre-Cambrian igneous intrusions and by the deposition of the post-Paleozoic formations of the Coastal Plain. The most northern intersection of the fault plane with the erosional surface is found on the boundary of the Octoraro schist, but it is likely that the original extent of the overthrust has been reduced by crustal shortening. That earth movements of similar extent are not uncommon is shown by a number of gently sloping overthrust fault planes in the southern Appalachian region. A fault in North Carolina and Tennessee, described by Keith,[1] extends over 100 miles in a northeasterly direction. The displacement along a gentle hade is estimated as at least 20 miles. The Rome fault[2] is another characteristic example of such an overthrust. Extending through Georgia and Alabama for many miles, it has thrust Cambrian shales over the underlying Silurian and Carboniferous rocks for more than 5 miles. An example of overthrusting on a much larger scale is seen in Scandinavia,[3] where the Archean crystalline schist has been moved over the Paleozoic formations for some 500 miles, with a horizontal displacement amounting to 80 miles. Similar overthrusts have been noted in the Eriboll dislocation zone, in northwestern Scotland,[4] in the Swiss Jura,[5] and in various other zones of intense folding. In all these localities the horizontal thrust plane has been folded along with the underlying rocks by subsequent diastrophism. In the Doe Run and Avondale region subsequent deformation has folded both underthrust and overthrust rocks, and although the massive Shenandoah limestone has in the main acted as a resistant formation, yet in some places the sharp folding has produced lines of structural weakness, and along these lines the plane of the major overthrust may have been dislocated by subsequent thrusts, although it was impossible to procure evidence for such subordinate faults of younger age.

Erosion combined with minor and major folding has cut the great thrust fault plane in a peculiarly irregular manner. The trace of its contact with the surface is therefore an extremely irregular line.

In this overthrust of the Wissahickon mica gneiss upon the Shenandoah limestone is found the explanation both of the superposition of mica gneiss upon limestone in the quarries of the district and also of the seemingly anomalous occurrence of younger formations in the valleys and older formations on the hilltops. (See fig. 4, p. 15.) The pitch of the formations to the northeast and southwest carries the fault plane below the surface, so that its extent along the line of strike can not be determined. Thinning out of the limestone owing to lack of sedimentation makes it impossible to determine the fault plane by the reappearance of the limestone at the surface, and its trace is lost in the Wissahickon mica gneiss.

JOINTS.

Jointing is a prominent feature of the rocks of the region. The pre-Cambrian gneisses have four important and persistent systems of joints, of which the three most pronounced are common to the Paleozoic rocks. The north-south joint system strikes from N. 15° W. to N. 10° E., and the east-west joint system strikes from N. 80° W. to N. 75° E. The dip of the planes

[1] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Roan Mountain folio (No. 151), 1907.

[2] Hayes, C. W., idem, Rome folio (No. 78), 1902.

[3] Högbom, A. G., Studies in the post-Silurian thrust region of Jämtland: Guide des excursions en Suède, tome I, No. 2, Eleventh Internat. Geol. Cong., 1910. Törnebohm, A. E., Geol. Fören. Förh., Bd. 10, p. 328-336, Stockholm, 1888.

[4] Geikie, Archibald, Geol. Soc. London Quart. Jour., vol. 44, pp. 378-441, 1888; based on field notes of B. N. Peach, J. Horne, W. Gunn, C. T. Clough, L. Hinxman, and H. M. Cadell.

[5] Rothpletz, August, Deutsche geol. Gesell. Zeitschr., Bd. 35, p. 134, 1883.

in both these systems is almost vertical, and the joints of the two systems, intersecting nearly at right angles, combined with the bedding plane, cut the rock into rhombohedral blocks. The third joint system, striking about N. 45° E., includes strike joints which are utilized as the back faces of quarries, as in the quartzite quarry on the north side of the road leading southwestward from London Grove, where a triple system of joints shows very distinctly. The fourth joint system, which strikes N. 45° W., is found in the Baltimore gneiss and Wissahickon mica gneiss.

HISTORICAL GEOLOGY.

PIEDMONT PLATEAU.

In order to understand the history of the Piedmont Plateau it is necessary to discuss that of the Appalachian region. A land area which has been called Appalachia existed along the present eastern border of the United States from pre-Paleozoic time, and its streams drained westward into the Appalachian Straits, an interior sea whose eastern shore was somewhere in the Piedmont Plateau and whose western shore was east of Mississippi River. The highly feldspathic shore material carried down by the Appalachian streams subsequently formed in the northern part of the Piedmont region the great expanses of Baltimore and Wissahickon gneiss, and in the southern part the thick deposits of Carolina gneiss. After the lapse of a period of time whose duration can be inferred only from the great thickness of pre-Cambrian sediments, a change in conditions set in. A gradual emergence of the land and a westward migration of the shore line took place, accompanied by igneous activity, during which large masses of granite, diorite, and pyroxenite were intruded into the pre-Cambrian gneisses, and a process of mountain building, similar to that which produced the Sierra Nevada and the Coast Range, was begun by the uplift of the deep-seated pre-Paleozoic rocks. The ancient Appalachian streams, rejuvenated by uplift, began to cut down through the newly formed land and once more found their way by lengthened courses to a sea which had migrated toward the west and was reduced to little more than a strait.

As the conditions of heat and pressure, which had led to igneous action, resumed an equilibrium, the widening waters of the Appalachian Straits slowly transgressed upon the shore lines of Appalachia in a period of submergence which lasted until the end of Ordovician time. Disintegrating feldspathic gneisses and igneous rocks furnished large pebbles of quartz and feldspar which were carried down by the streams and dropped along a receding shore line, forming the basal conglomerate that marks the close of the period of erosion that resulted in the pre-Cambrian unconformity and the beginning of a long period of quiet sedimentation. North of Philadelphia, traces of this conglomerate, exposed by the upward pitch of a syncline, underlie a fine-grained white quartzite which represents the Lower Cambrian and which extends in varying thickness and amount throughout the Piedmont region. At the beginning of Cambrian time a slow subsidence of the upland was flooding the stream valleys at their mouths, forming estuaries in which was deposited shore material of coarse sand, often impure, because wave action was not sufficient to sort the material. In the northern part of the Piedmont region this sand by consolidation and metamorphism has become quartzite, or mica schist, or mica gneiss; in the south, with little or no metamorphism, it has become sandstone and shale. Its thickness is variant owing to changes in level of the strand line during deposition.

These local oscillations next gave rise to a deposit in which micaceous mud alternates with sand. Subsequent continuous erosion of the Appalachian land brought to the sea finer and finer sediments, and over the Lower Cambrian quartzite calcareous deposits were laid down in a transgressing sea, so that gradual denudation of the land, accompanied by an expanding and deepening of the sea, resulted in a thick accumulation of late Cambrian and Ordovician limestone, the Shenandoah limestone. Conditions remaining unchanged, the Cambrian period passed into the Ordovician without stratigraphic break, so that it is only by study of the changes in marine life that the periods can be separated. In later Ordovician time there was a negative displacement of the strand line and the positive element, Appalachia, once more increased in extent, while in the west a Cambrian island was elevated above the interior sea and formed the Cincinnati arch. The streams, quickened by rejuvenation, carried down from the late Cambrian and Ordovician lowlands large quantities of a fine clayey mud and deposited it conformably upon the limestone, forming the Ordovician shale, which produced the Martinsburg shale of the southern Piedmont area, and probably by later metamorphism the Octoraro schist of the northern Piedmont.

The emergence that marked the close of the great period of limestone deposition continued in this region until the close of the Paleozoic era, while elsewhere a varying succession of sand and shale was laid down. At first shale succeeded limestone in all parts of the region, but when the uplift was accomplished the shale was confined to deeper-water sedimentation. Uplift continued until the Appalachian Sea was closed at the north and became a gulf.

In the southeastern Piedmont belt of Pennsylvania no sediments younger than Ordovician are found. Silurian and Devonian sediments may have been laid down and later removed by erosion, but it is likely that this area, during the deposition of the coal measures in western lagoons, was a land mass which received no further sediments until the end of the Triassic period. The Appalachian Gulf was being slowly filled, and the shore line was moving west, until, at the end of Carboniferous time, marine sedimentation in the Appalachian Straits was brought to an end.

During the post-Carboniferous period of erosion the uplifted continent was worn down by the degradation of upper Paleozoic sediments, so that if any post-Ordovician Paleozoic formations were ever present in the Piedmont Plateau they were completely removed. A slow transgression upon the eastern shore of the Appalachian continent followed the emergence of the western coast from the interior Paleozoic sea. Exactly where the Atlantic coast line stood in Mesozoic time can hardly be determined, but the evidence of the deposits of the Newark group would indicate that toward the end of the Triassic period a series of lagoons and tidal estuaries extended along the eastern border of the continent, then worn down to the level of Ordovician sediments. In the shallow, brackish water of these lagoons rivers were depositing the mud and sand from the eroded Paleozoic rocks which subsequently formed the ripple-marked red shales and sandstones of the Newark group. Volcanic activity accompanied the sedimentation, resulting in flows of basic lava and in the intrusion of sills and dikes of diabase which extend with various interruptions from the great Palisades of New York to isolated dikes in Maryland. With the emergence of the Newark sediments the last sedimentation distinctive of the Piedmont Plateau came to a close. The history of all succeeding deposits may be read in the adjoining Coastal Plain province.

DOE RUN AND AVONDALE REGION.

The formations of the Doe Run and Avondale region present an epitome of the geologic history of the Piedmont Plateau from early pre-Cambrian through Ordovician time. In order to understand the somewhat irregular sedimentation of this area the conditions of deposition must be clearly borne in mind. It will be remembered that the Appalachian continent, worn by erosion to a region of low relief, lay to the east of the present Piedmont district, and the interior sea, which had widened in the south probably as far east as the present Atlantic shore and had migrated in the west across the great Appalachian Valley to Missouri and Wisconsin, was rapidly narrowing in its northern part to little more than a strait. The sediments which form the Wissahickon mica gneiss were being laid down in a thick deposit along the shore line of Appalachia. That the southern portion of the Doe Run and Avondale region remained, in part at least, a land mass until the beginning of Cambrian time is a conclusion suggested by the absence of the Wissahickon mica gneiss between the Baltimore gneiss and the Cambrian quartzite in the Woodville-Chatham anticline, and by the presence on the flanks of the igneous core of a sedimentary transition facies of the Baltimore gneiss. Pumpelly[1] has described a gneiss from Hoosac Mountain, Vt., which presents the same anomalous feature—that of a transitional form apparently in direct continuity with two formations otherwise separated by a great time break and an erosional unconformity. He explains the gneiss of Hoosac Mountain as a local consolidation of

[1] Pumpelly, Raphael, The relation of secular rock disintegration to certain transitional crystalline schists: Geol. Soc. America Bull., vol. 2, pp. 209-224, 1890.

decayed rock material; according to him the consolidations favorable for deep rock disintegration are "a land surface exposed during a long period to the influence of a moist climate and protected by vegetation."

Toward the end of pre-Cambrian time the land surface of the Avondale district had reached an advanced stage of disintegration similar to that described by Pumpelly as consisting of three zones. On the surface was a layer of kaolinized material, forming a clay; between the semikaolinized material and the fresh rock was a zone in which the process of disintegration had advanced only far enough to weaken mineral cohesion by alteration of the micaceous or hornblendic layers. A residual soil produced under such conditions would remain in place, forming a deep zone that would grade insensibly into a layer in which disintegration had not been accompanied by decay.

That compressive stress was already acting upon the Baltimore gneiss of the Pennsylvania Piedmont is shown by the intrusions of gabbroitic magma now found in the pre-Cambrian gneiss; at the same time folding and metamorphism were taking place, thereby giving a gneissic character and simulated conformity to both igneous and sedimentary formations. During this period of stress the semidisintegrated material in the zone of weakened cohesion, overlying the true gneiss, yielded readily to pressure and was consolidated, assuming the gneissic structure of the parent rock.

The transgression which ushered in the Cambrian period was contemporaneous with the development of the thrust force which metamorphosed pre-Cambrian rocks into gneisses. The residual clay soil, washed away by the rapidly advancing waves, was deposited in deep water far from the shore; the coarse semikaolinized material, an easy prey to erosion, was carried to the sea and deposited near the shore, subsequently forming the conglomerate that marks the base of the Cambrian; the removal of these two upper zones exposed the lower beds of secularly disintegrated rock that had been consolidated in place; and by the erosion of this transitional gneiss material was furnished for the formation that was later consolidated and metamorphosed into the Lower Cambrian mica gneiss of the Chickies formation.

During later Cambrian and Ordovician time the sedimentation of the Doe Run and Avondale region was quiet and continuous, uninterrupted by any marked disturbance. Streams working in the pre-Cambrian gneisses of the northern and southern areas were cutting out a fine quartzose sand which was deposited at river mouths in deepening estuaries.

Submergence continued without local uplift, so far as the evidence shows, and deepening water in Upper Cambrian time received the wide limestone deposit which continued into the Ordovician period and probably extended over the whole surface of the Doe Run and Avondale region. A slight negative movement of the strand line ensued, and a load of fine mud was poured into the clear waters of streams that had been carrying lime in solution. The first result of the change in stream content was the deposition of a calcareous shale upon the surface of the limestone. On further uplift erosion washed down from the lowlands large quantities of finely divided clayey material, which was subsequently consolidated to a shale and metamorphosed to the Octoraro schist. Deposition of Silurian sediments upon the Ordovician shale seems probable, but all positive evidence of such sedimentation has been removed by subsequent erosion. In the southern part of Pennsylvania adjacent to the Piedmont Plateau, as estimated by Stose,[1] the total thickness of the Paleozoic sediments is 20,000 feet, and about 4,000 feet of this thickness represents post-Martinsburg sedimentation; it is therefore probable that in the Doe Run and Avondale region a light load of sediments may have covered the Ordovician shales.

In the pre-Cambrian sea southeast of the Doe Run and Avondale region the Wissahickon mica gneiss had been deposited in the form of an arkosic argillite, which during the late pre-Cambrian period of diastrophism was consolidated and metamorphosed. Before the beginning of the Paleozoic era the Wissahickon gneiss suffered erosion in the pre-Cambrian mountains of Appalachia, and when the western part of Appalachia was buried beneath Paleozoic sediments the gneiss was brought into the zone of anamorphism and was subjected to the

[1] Stose, G. W., The sedimentary rocks of South Mountain, Pa.: Jour. Geology, vol. 14, pp. 201-220, 1906: U. S. Geol. Survey Geol. Atlas, Mercersburg-Chambersburg folio (No. 170), 1909.

compressive forces that operated throughout the Paleozoic era. Through the whole of early Paleozoic time a slowly accumulating earth stress was making itself felt in deeply buried sediments. The resistant power of the Shenandoah limestone, combined with its extent, made it a competent stratum in the process of folding. According to C. W. Hayes [1] the requisites for great overthrust movements are a light load upon a competent stratum. The Shenandoah limestone at first offered the requisite resistance to the strong thrust force, and later, after it had been folded into gentle open folds, it gave way to the accumulating stress which thrust the Wissahickon gneiss, originally deposited on the western shore of Appalachia, far over the surface of the folded limestone.

From a study of the structure in the Doe Run and Avondale region it seems probable that there were two periods of folding during Paleozoic time. It is an accepted fact that the Appalachian Mountains are a pre-Permian range which is connected, by way of the mountains of Newfoundland and Nova Scotia, with the pre-Permian mountains of Europe—the Armorican-Variscan ranges. In the Piedmont Plateau the effects of the pre-Permian diastrophism which formed these mountains are seen in the folding and faulting of the Paleozoic formations. In Scandinavia, Scotland, and Ireland the Armorican Mountains follow the line of an older range—the pre-Devonian Caledonian Mountains. The pre-Cambrian platform in the Caledonides, according to Peach and Horne,[2] "has been driven forward until the Archean rocks have been carried over the truncated edges of the Silurian strata." In the Scottish Highlands the presence of Lower Devonian strata, unaffected by this period of thrusting and faulting, makes evident the age of the movement. In the Piedmont Plateau there is a similar series of pre-Cambrian and Cambrian and Ordovician rocks. Here also an overthrust has brought pre-Cambrian gneiss over Paleozoic sediments, but in the Doe Run and Avondale region erosion has removed the Silurian and post-Silurian rocks, so that proof of the age of the thrusting can not be found in the presence of undisturbed material.

[1] Hayes, C. W., The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., vol. 2, pp. 141-154, 1891.

[2] Peach, B. N., and Horne, J., Nature, vol. 31, p. 33, November, 1884; see also London Geol. Soc. Quart. Jour., vol. 44, p. 378, 1888.

In Brazil and in northwestern Europe there are pre-Devonian mountains whose formation was due to the same cause—tangential compression derived from suboceanic spread. It is probable that this compression affected Appalachia, the great positive element of the eastern Atlantic region, as well as the northern and southern Atlantic regions, though the resulting diastrophism may not have been exactly contemporaneous. Schuchert considers the Taconic revolution (the pre-Silurian period of folding and thrusting in eastern America) the most marked disturbance of the era except the Appalachian revolution; it may be that the time of thrusting in Appalachia was pre-Silurian, instead of pre-Devonian, corresponding to the age of the Caledonides in northern Africa. It is possible that the thrusting was a gradual movement which kept pace with the deposition that probably occurred in eastern Pennsylvania during Devonian time. By the end of the Carboniferous period a reaccumulated earth stress once more found relief in a period of folding by which the already overthrust gneiss was folded along with the underlying rocks.

To these Paleozoic earth stresses, therefore, the rocks of the Doe Run and Avondale region owe their present complicated and overturned structure, which was already established before erosion had carried its work so far as to expose to view the Ordovician schist. Upon the degraded surface of this schist later Tertiary and Quaternary deposits have been laid down and again completely removed by erosion.

The fact that these deposits once extended over the whole region is proved by the character of the underlying drainage. The courses of the larger streams show them to be out of adjustment to the underlying formations, and such a discordance can be explained only as a superimposition of drainage inherited from a cover of material that was sufficiently deep to establish the streams firmly in their present courses.

CONCLUSION.

Nowhere in the Piedmont Plateau does the Wissahickon mica gneiss have easily interpreted relations to other formations. Near Philadelphia it is in contact with the Baltimore gneiss, an ancient pre-Cambrian formation which served as a floor for sediments of later age, or it is adjacent to younger sedimentary material from which it is separated by faulting. Elsewhere in this paper it has been stated that the Wissahickon mica gneiss and the Octoraro schist are in contact in the Doe Run region and the immediately adjoining area. The question of their age and of their structural relations has been a moot point, not only because of the difficulty in determining the age of the Wissahickon gneiss but also on account of the ambiguous structural relations existing between the mica gneiss and the Ordovician limestone. In the Coatesville quadrangle small outcrops of limestone occurring within the mica gneiss exhibit a relation which has a significant bearing upon the problem of the age of the mica gneiss.

The age of the limestone must be first determined, but absence of fossils, metamorphism, and complicated structural relations make this determination difficult. The limestone may belong to the pre-Cambrian and be the equivalent of the Franklin limestone toward the east, or it may be the representative of the Cambrian and Ordovician Shenandoah limestone. The limestone of the Doe Run and Avondale region is lithologically dissimilar to the Franklin limestone, and it is not associated with graphitic gneiss, which usually accompanies the Franklin limestone. On the other hand, the limestone of the Doe Run and Avondale region bears a complete lithologic resemblance to the Shenandoah limestone of Chester Valley. It occurs in a conformable series with a quartzite which has been correlated with the Chickies quartzite of the North Valley Hills. Moreover, the southern limestone areas of the Doe Run and Avondale region are in the direct line of strike with the Shenandoah limestone of Cream Valley, west of Conshohocken. For these reasons the limestone of the region under discussion is correlated with the Shenandoah.

The readily determined relation between the Ordovician mica schist and the great belt of Shenandoah limestone, which has been proved by fossil content to be of Cambrian and Ordovician age, establishes the age of the mica schist as Ordovician.[1] The conformable contact of the schist upon the limestone is shown by the lithologic gradation of the limestone through a calcareous mica schist into the overlying formation, as seen in Chester Valley near Coatesville, and also by the constant presence of a single bed of geodiferous, siliceous material along the line of contact,[2] thereby proving that the contact can not be a fault line.

The fact that no fossils have been found in the Wissahickon mica gneiss makes it necessary in determining its age to rely altogether upon its stratigraphic relations to other formations. In dealing with the relations of the mica gneiss to the Ordovician Octoraro schist it must be decided whether the gneiss is of the same age as the schist and grades into it, or whether the gneiss is of different age from the schist and is separated from it by a thrust fault. The evidence in the Doe Run and Avondale region seems to indicate a difference in age notwithstanding a marked resemblance between the two formations. A certain resemblance between the gneiss and the schist, both in the hand specimen and in the field, has caused considerable difficulty in distinguishing them and has given rise to the supposition that the mica gneiss is probably of Ordovician age. On close examination, however, it becomes evident that the apparent gradation of gneiss into schist across the line of strike is not actual. A detailed study of the region has established both lithologic and structural differences, shown by the following facts which have been used as a lithologic basis of separation between the two rocks:

1. The mica gneiss always contains feldspar, usually in large amounts; the mica schist is almost free from feldspar.

2. The gneiss shows close crumpling and many fine plications; the schist is straight bedded.

3. The gneiss is garnetiferous; the schist is not.

4. The gneiss shows evidence, in coarser crystallinity, of having undergone greater metamorphism than the schist; and the change in metamorphism is too abrupt and well marked to be explained as the result of gradual eastward increase of the metamorphic action that prevailed throughout the Piedmont Plateau.

5. The chemical analysis of the gneiss shows the composition of an arkose which has under-

[1] Merrill, F. J. H., U. S. Geol. Survey Geol. Atlas, New York folio (No. 83), p. 4, 1902. Bascom, Florence, idem, Philadelphia folio (No. 162), p. 5, 1909.

[2] Bascom, Florence, idem.

gone injection and impregnation, while the schist has the composition of an argillite.

6. The dip of the gneiss is gentle, about 30°; that of the schist averages about 60°.

7. There are four well-marked joint systems in the gneiss, whereas the schist possesses only three joint systems.

The coarser crystallinity of the gneiss and the development of deep-seated metamorphic minerals not found in the schist, together with the presence in the gneiss of one joint system and many plications that are absent in the Ordovician material, are evidences that the mica gneiss has been subjected to the influence of one more period of diastrophism than the schist and is therefore much older than Ordovician.

As the Wissahickon gneiss must be older than Ordovician, let us examine the stratigraphic column in the Doe Run and Avondale region in order to decide at what horizon the gneiss is most likely to belong. It can not be considered younger than the limestone—that is, underlying the schist and overlying the limestone—because of the conformity which has been established between the limestone and the mica schist. That the mica gneiss can not be included within the Shenandoah limestone is shown by the prevalent calcareous nature of the Shenandoah deposits seen in the Great Valley and in the Piedmont region of eastern Pennsylvania. The generally conceded conformity between the Lower Cambrian deposits and the Shenandoah limestone excludes the gneiss from a position between the limestone and the quartzite and proves that the Wissahickon is as old as or older than the Chickies formation.

It therefore remains to be considered whether there is sufficient evidence to warrant the inclusion of the Wissahickon gneiss in the Paleozoic succession by placing it within the Lower Cambrian. The character of the Wissahickon and the absence of similar rock within the Lower Cambrian of other regions make it seem unlikely that a great thickness of arkosic material may be included within Lower Cambrian rocks, which elsewhere in the Appalachian province indicate a persistently arenaceous sedimentation.

It has been shown that the mica gneiss can not be younger than the Shenandoah limestone, that is, of Ordovician age—and also that it can not be of Cambrian age; hence by exclusion from the Paleozoic succession the mica gneiss becomes pre-Cambrian. Positive evidence of this age is found in the relation which the igneous intrusives bear to the Wissahickon formation. The mica gneiss is penetrated by granite, gabbro, and ultrabasic intrusive rocks whose horizon is bounded by pre-Cambrian rocks. These intrusive rocks are found in the Baltimore gneiss and the Wissahickon mica gneiss, but are not found to a significant extent in Paleozoic rocks of known or questionable age. The Paleozoic rocks are therefore separated from the Wissahickon mica gneiss by an unconformity which determines the pre-Cambrian age of the mica gneiss.

A further confirmation of the pre-Cambrian age of the Wissahickon gneiss is the fact that the formation can be traced westward from the Doe Run and Avondale region through southeastern Pennsylvania into Maryland and thence into the District of Columbia and Virginia. The formation in the neighborhood of Washington which is lithologically similar to the mica gneiss of Doe Run and Avondale has been described by Keith [1] as the Carolina gneiss and determined as pre-Cambrian.

The Shenandoah limestone on the south side of the Cabin John and Buck Ridge anticline has been folded into a syncline which is made up of many secondary folds. The Wissahickon mica gneiss occupies the center of many of these synclines, most of which are overturned toward the northwest, giving the strata isoclinal dips. In order to explain the presence of a pre-Cambrian gneiss in immediate contact with the Cambrian and Ordovician limestone and the Ordovician schist it is necessary to assume the existence of a deep overthrust fault, the origin and nature of which have been described and which has brought the older formation along a gentle hade to lie upon the younger Paleozoic rocks. The resulting discordance has been obscured by a subsequent diastrophic movement that has folded and faulted the thrust plane as if it were a plane of stratification.

In the neighborhood of Philadelphia Miss Bascom [2] has established two presumably continuous fault lines along Huntingdon and Cream

[1] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Washington folio (No. 70), p. 2, 1901.

[2] Bascom, Florence, U. S. Geol. Survey Geol. Atlas, Philadelphia folio (No. 163), p. 16, 1909.

valleys. The Cream Valley fault has brought up the Buck Ridge anticline of pre-Cambrian gneiss until it overlies the syncline in the Ordovician schist. The westward continuation of this fault lies along the contact of the Wissahickon gneiss and Octoraro schist and extends directly into the Doe Run region. The change in dip between the schist and the gneiss is structural confirmation of the existence of a fault which is in complete accord, not only with the prevalent type of Piedmont structure as determined in the eastern Atlantic States, but also with the structure of regions similar to the Piedmont of the United States—for example, northern Scotland and Scandinavia, where overthrusting of like character and magnitude has been worked out.

Therefore, as the existing evidence seems to indicate a pre-Cambrian age for the Wissahickon mica gneiss, and as the structure necessary to explain the relations of the gneiss to the Paleozoic sediments is in keeping not only with the intrinsic structural evidence of the formations but also with the structure of regions similar to the Piedmont of Pennsylvania, it seems fair to conclude that the Wissahickon mica gneiss is separated from the Shenandoah limestone and the Octoraro schist by a thrust fault which has been obscured by post-Ordovician metamorphism.

RETREAT OF BARRY GLACIER, PORT WELLS, PRINCE WILLIAM SOUND, ALASKA, BETWEEN 1910 AND 1914.

By Bertrand L. Johnson.

The Barry Glacier, in the northwest corner of Prince William Sound (fig. 6), was first described by Glenn,[1] Castner,[2] and Mendenhall.[3] It was more extensively studied by the Harriman Alaska expedition[4] in 1899; by Grant[5] in 1905; by Grant and Higgins[5] in 1908 and 1909; and by Martin[6] in 1910. In 1899 Gannett made the first map which accurately delineated the front of the Barry Glacier. The front was remapped by Grant in 1905, by Grant and Higgins in 1908 and 1909, and by Martin in 1910. Numerous photographs were taken in these years, and several of them were reproduced in the reports cited. Tarr and Martin[7] summarized the results of the earlier expeditions and gave an exhaustive treatment of the known life history of the Barry Glacier up to and including 1910. In 1899 the Barry Glacier nearly closed Doran Strait. (See fig. 7.) In 1910, when the National Geographic Society's expedition under Lawrence Martin mapped and studied the front

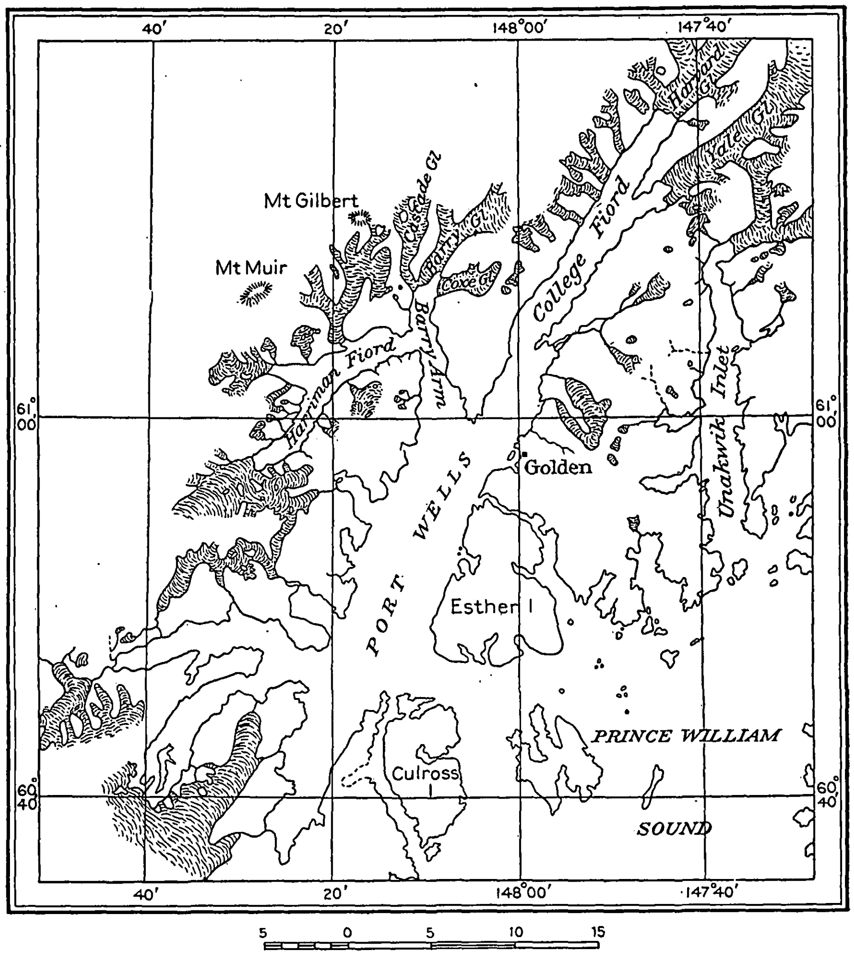


Figure 6.—Map of the Port Wells district, Prince William Sound, Alaska, showing location of Barry Glacier.

[1] Glenn, E. F., Report on exploration in Alaska: U. S. War Dept., Adj. Gen. Office, No. 25, pp. 19, 21, 1899.

[2] Castner, J. C., idem, pp. 189, 191.

[3] Mendenhall, W. C., A reconnaissance from Resurrection Bay to the Tanana River, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 325, 1900.

[4] Gannett, Henry, The Harriman Alaska Expedition: Nat. Geog. Mag., vol. 10, pp. 510, 511, 1899; Am. Geog. Soc. Jour., vol. 31, pp. 355–356, 1899, Burroughs, John, Narrative of the expedition: Alaska, vol. 1, pp. 71–74. Harriman Alaska Expedition, 1902. Gannett, Henry, General geography: Idem, vol. 2, p. 263, 1902. Gilbert, G. K., Glaciers and glaciation: Idem, vol. 3, pp. 90–93, 176, 1904.

[5] Grant, U. S., and Higgins, D. F., Glaciers of Prince William Sound and the southern part of the Kenai Peninsula, Alaska; II, Glaciers of Port Wells, Prince William Sound: Am. Geog. Soc. Bull., vol. 43, pp. 327–331, 334, 1911; Coastal glaciers of Prince William Sound and Kenai Peninsula, Alaska: U. S. Geol. Survey Bull. 526, pp. 33–35, 1913. Reid, H. F., The variations of glaciers: Jour. Geology, vol. 14, pp. 406–407, 1906; vol. 17, p. 671, 1909.

[6] Martin, Lawrence, Crossing the Alaskan glaciers: Collier's, vol. 47, No. 17, p. 20, July 15, 1911; The National Geographic Society's researches in Alaska: Nat. Geog. Mag., vol. 22, pp. 550–551, 555, 556, 557, 559, 560, 1911; Gletscheruntersuchungen längs der Küste von Alaska: Petermanns Mitt., Jahrg. 58, pp. 82, 148–149, 1912. Reid, H. F., Les variations périodiques des glaciers, XVIme rapport, 1910—Amérique du Nord: Zeitschr. Gletscherkunde, Bd. 6, Heft 2, pp. 101–102, 1911; The variations of glaciers: Jour. Geology, vol. 19, p. 458, 1911. Tarr, R. S., and Martin, Lawrence, Alaskan glacier studies, pp. 14, 317, 319–327, 348–349, 350, Nat. Geog. Soc., 1914.

[7] Tarr, R. S., and Martin, Lawrence, op. cit., pp. 318–327.

of the glacier, it had retreated approximately 3 miles from the position occupied in 1899.

The Barry Glacier was visited by the writer in 1913 and again late in the fall of 1914. Photographs were taken in both years, and four of these photographs are reproduced here (Pls. V and VI) for comparison with two photographs (Pl. IV) by Lawrence Martin, showing the position of the ice front in 1910. The positions of the glacier front in 1899, 1905, 1908, 1909, 1910, 1913, and 1914 are shown in the accompanying sketch map (fig. 7).

The glacier front in 1910 stretched in a nearly straight line across Barry Arm (fig. 7 and Pl. IV). Between 1910 and 1913 the retreat of the glacier uncovered bedrock in the western part of the glacier front, near the left center of the view shown in Plate V, *A*. No rock outcrops are visible in the photographs made in 1910 (Pl. IV), nor does Martin mention any exposed bedrock in the glacier front. As an apparent result of this uncovering of the bedrock surface the western part of the glacier front retreated less rapidly than the eastern part, and in 1913 a marked reentrant was noticeable along the east side of the glacier.

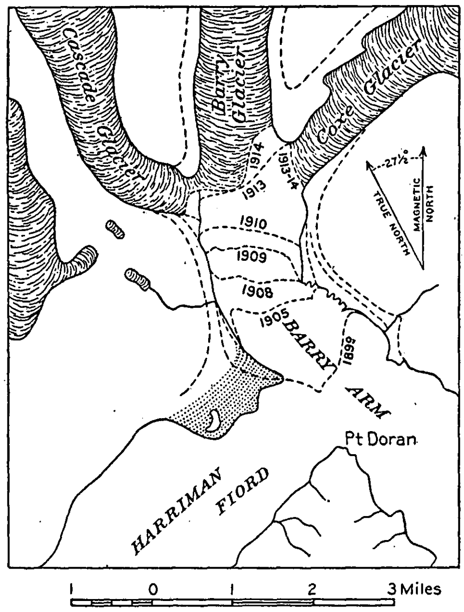
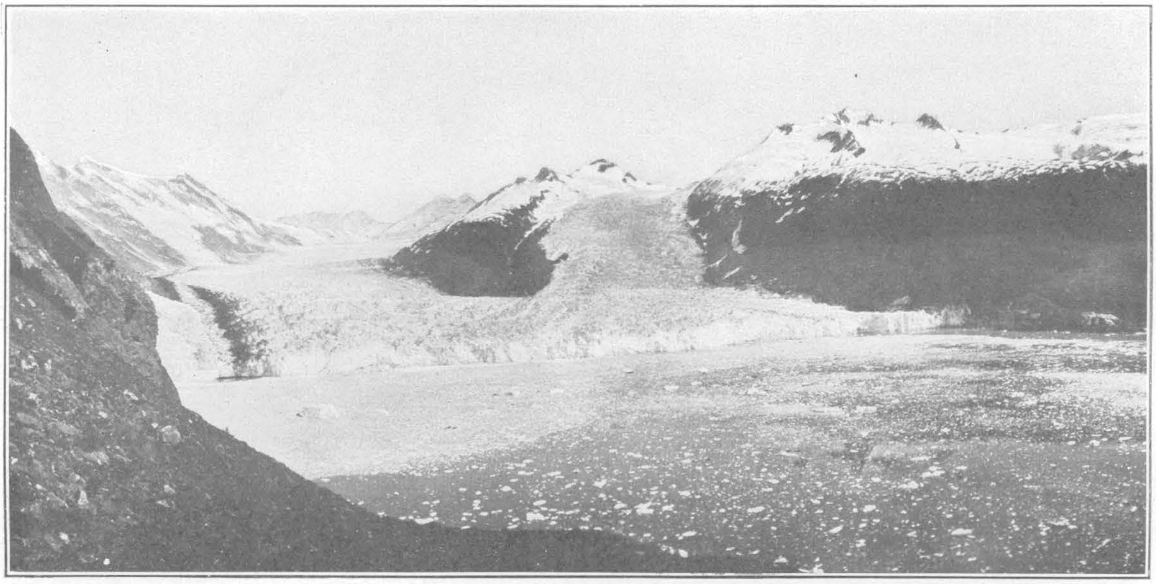


FIGURE 7.—Sketch map of Barry, Coxe, and Cascade glaciers, Prince William Sound, Alaska, showing position of glacier fronts in 1899, 1905, 1908, 1909, 1910, 1913, and 1914.

On this side the Barry Glacier had also retreated beyond the Coxe Glacier and was completely separated from it (Pls. V, *A*, and VI, *A*). The Barry and Cascade glaciers had partly separated (Pl. VI, *A*). The surface of the Barry Glacier at its outer end had also lowered, increasing the width of the bare zones at the sides of the glacier by an appreciable amount. The linear retreat along the east side of the glacier between 1910 and 1913 is estimated as about 6,500 feet; that along the west side as about 2,500 feet. The average annual retreat between 1910 and 1913 was thus slightly over 2,100 feet on the east side but only a little over 800 feet on the west side. The rate of retreat on the west side, however, was probably much greater prior to the exposure of bedrock in the glacier front, as between 1905 and 1910 the receding glacier preserved a nearly straight front across Barry Arm. The inference that the rate of retreat on the west side rapidly lessened after the uncovering of bedrock in that portion of the glacier front is borne out by the slight retreat at this point between 1913 and 1914.

The photographs taken in the fall of 1914 show a continued withdrawal of the glacier, most rapidly along its east side, where the distance between the Barry and Coxe glaciers had increased conspicuously (Pl. V, *B*). The retreat here between the dates in 1913 and 1914 on which the photographs were taken appeared to be about 1,700 feet. The bedrock in the western part of the Barry Glacier front was still visible, and appeared to be of about the same height as in 1913 but to have a slightly greater length along the glacier front. The ice at this point had apparently retreated but slightly since 1913. The separation of the Cascade and Barry glaciers was more nearly complete, and that part of the Cascade Glacier already separated from the Barry Glacier had retreated a short distance up the fiord wall (Pl. VI, *B*). The surface of the Barry Glacier was considerably lower, and that of the Coxe Glacier had lowered slightly. The total retreat of the Barry Glacier between 1910 and 1914 appeared to be about 8,200 feet along its eastern edge and a little more than 2,500 feet along its western edge.

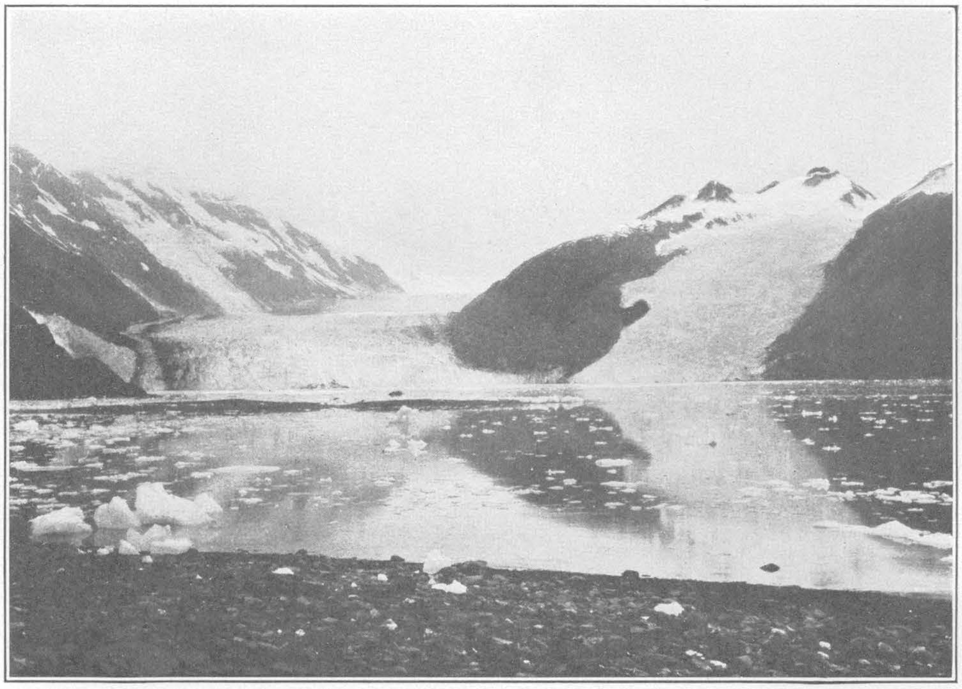


A. BARRY AND COXE GLACIERS, JULY 26, 1910.

Photograph by Lawrence Martin. Originally reproduced in Tarr and Martin's "Alaskan glacier studies." Used by courtesy of the National Geographic Society.

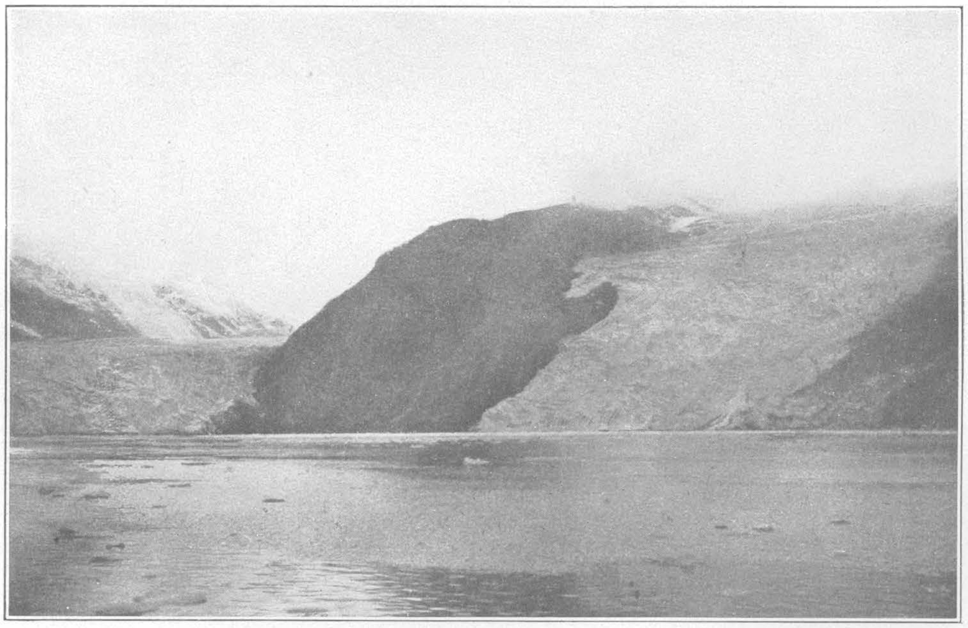
B. CASCADE GLACIER AT ITS JUNCTION WITH BARRY GLACIER, JULY 25, 1910.

Photograph by Lawrence Martin. Originally reproduced in Collier's, vol. 47, No. 17, July 15, 1911.



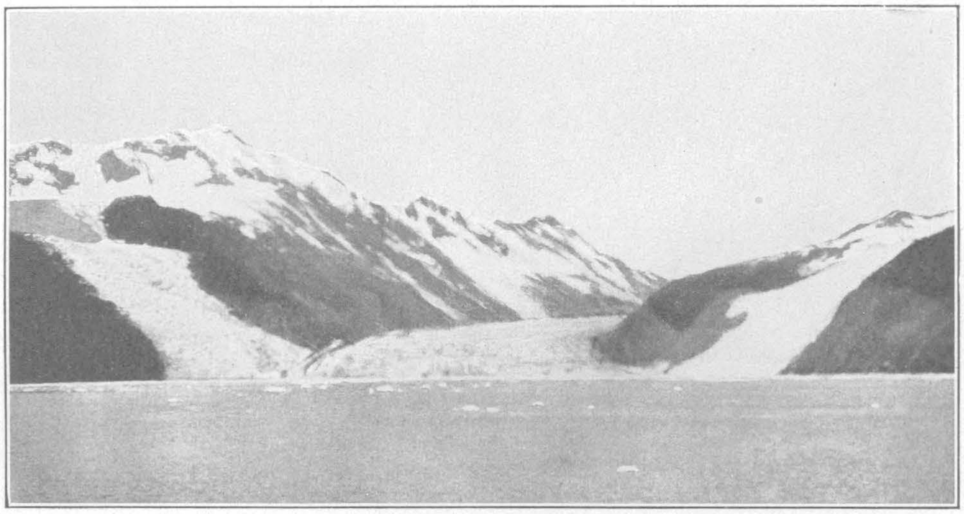
A. BARRY AND COXE GLACIERS, AUGUST 18, 1913.

From outwash plain formed by Barry Glacier in 1899. (See fig. 7.) Note outcrop of rock in front of Barry Glacier and separation of Barry and Coxe glaciers. Photograph by B. L. Johnson.

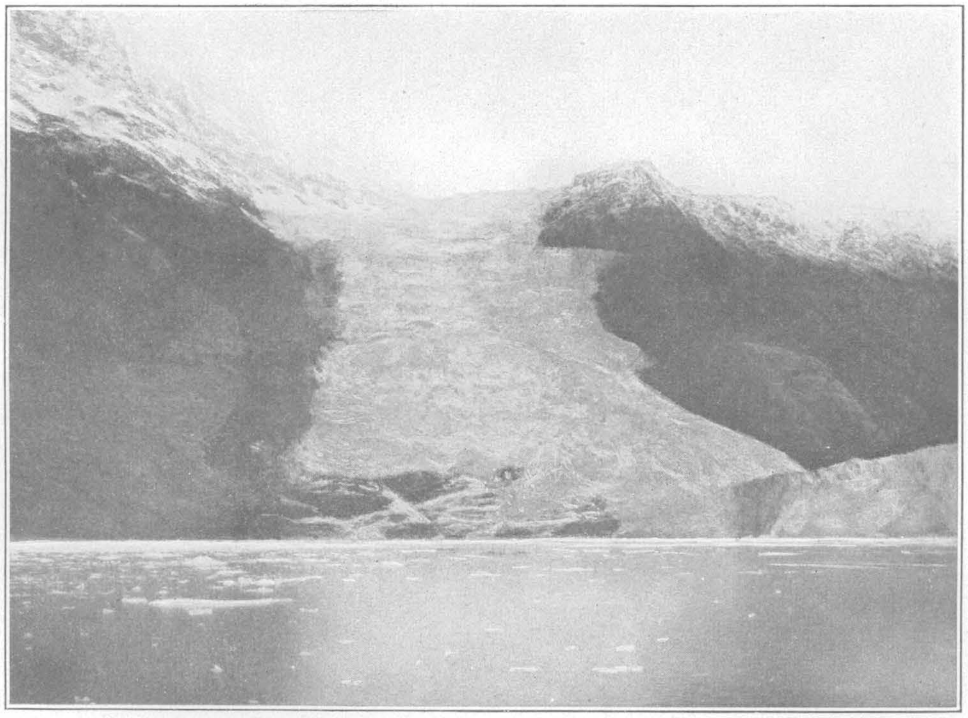


B. BARRY AND COXE GLACIERS, OCTOBER 5, 1914.

Glaciers are much more widely separated than in previous years. Photograph by B. L. Johnson, from deck of a launch.



A. BARRY, COXE, AND CASCADE GLACIERS, AUGUST 15, 1913.
Photograph by B. L. Johnson, from deck of a launch.



B. CASCADE GLACIER AT ITS JUNCTION WITH BARRY GLACIER, OCTOBER 5, 1914.
Glaciers are almost separated, and Cascade Glacier has begun to retreat up the fiord wall.
Photograph by B. L. Johnson, from deck of a launch.

EXPERIMENTS ON THE EXTRACTION OF POTASH FROM WYOMINGITE.

By Roger C. Wells.

INTRODUCTION.

The United States Geological Survey has now made a considerable number of explorations in search of a domestic source of potash and further explorations are under way. In the meantime the Survey has studied the chemical and physical characteristics of the rocks, minerals, and salines so far discovered, and it is the object of the present paper to describe laboratory experiments made with the rock wyomingite.

Wyomingite, a lava occurring extensively in the Leucite Hills in Sweetwater County, Wyo.,[1] is composed largely of the mineral leucite, a silicate of alumina and potash. Leucite is far richer in potash than feldspar, which is commonly regarded as one of the most promising prospective sources of potash. Moreover, the potash in leucite, although not soluble in water, seems to be more easily attackable by reagents than that in feldspar, so that if any igneous rock should become a source of potash wyomingite would have advantages over a feldspar-bearing rock. Data on the properties of wyomingite will therefore be valuable. While all the experiments to be described here can not be considered as suggestions of commercial possibilities, a record of them may not only be suggestive to private investigators, but save much repetition of preliminary investigation.

CHEMICAL COMPOSITION OF WYOMINGITE.

The wyomingite used in the experiments to be described has the following composition:

Composition of wyomingite.[2]

[W. F. Hillebrand, analyst.]

Silica (SiO_2)	53.70
Titanic acid (TiO_2)	1.92
Alumina (Al_2O_3)	11.16
Ferric oxide (Fe_2O_3)	3.10
Ferrous oxide (FeO)	1.21
Magnesia (MgO)	6.44
Lime (CaO)	3.46
Soda (Na_2O)	1.67
Potash (K_2O)	11.16
Water (H_2O)	3.41
Phosphoric acid (P_2O_5)	1.75
Sulphur trioxide (SO_3)	.06
Fluorine (F)	.44
Other constituents	.92
	100.40

Specific gravity, 2.627.

This rock was obtained near Fifteen-mile Spring, on the northeast side of Zirkel Mesa. It is the typical dense reddish-brown wyomingite, such as occurs in many of the mesas and hills of this region.

MINERAL COMPOSITION OF WYOMINGITE.

According to Cross[3] this wyomingite really consists of the following minerals: Uncombined silica, 22.5 per cent; leucite, 35.7 per cent; phlogopite, 22.3 per cent; diopside, 10.7 per cent; and accessory minerals, 8.8 per cent. The potash content of wyomingite is distributed among leucite, phlogopite, and a glassy base which is chiefly uncombined silica. There is enough uncombined silica in wyomingite to have formed a feldspar, and why leucite was formed instead has not yet been explained.

[1] The quantity of leucite-bearing rock present at this locality is estimated at nearly 2,000,000,000 tons, containing an average of 10 per cent of potash. See U. S. Geol. Survey Bull. 512, p. 35, 1912.

[2] Clarke, F. W., Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1880-1914: U. S. Geol. Survey Bull. 591, p. 74, 1915.

[3] Cross, Whitman, Igneous rocks of the Leucite Hills and Pilot Butte, Wyo.: Am. Jour. Sci., 4th ser., vol. 4, p. 133, 1897.

On the assumption that in any process of extraction this silica can be kept from combining with the potash, the advantage inherent in the wyomingite can be seen at a glance by comparing the theoretical percentage of potash in leucite with that in orthoclase feldspar, leucite ($K_2O.Al_2O_3.4SiO_2$) containing 21.5 per cent and orthoclase ($K_2O.Al_2O_3.6SiO_2$) 16.9 per cent.

BEHAVIOR OF CRUSHED WYOMINGITE IN WATER.

As leucite has a specific gravity of 2.45 to 2.50, while the specific gravities of phlogopite, diopside, and silica are 2.7, 3.3, and 2.6, respectively, it was hoped that some separation of the lighter and more valuable mineral could be made by a flotation process. A small amount of wyomingite was crushed to pass an 80-mesh screen and separated into two portions, one heavier and one lighter, by panning with water. Each of these portions was panned similarly. The combined lighter portions weighed 0.93 gram and the heavier portions 0.60 gram. The lighter portion was analyzed with the following results:

Effect of panning wyomingite.

	Original rock.	Lighter portion.
K_2O .... per cent..	11.2	12.1
Na_2O .... do....	1.7	1.1

Although the effect was not as great as desired it is evident that the method of concentration used caused some separation of the leucite from the other minerals. According to Cross, wyomingite is a very fine grained rock, so that it may be too much to expect that a mechanical method of concentration will effect a complete separation, but if such a method could be discovered, it would render an enormous quantity of mineral having a high potash content available for chemical treatment.

Cold water attacks leucite somewhat, but the action is so slight that the fact has scarcely any significance unless it is in agricultural chemistry. When certain other salts are present in the water, however, the action is somewhat more noticeable. This was shown by some experiments carried out with wyomingite and gypsum, 10 grams of each, powdered, being placed in 500 cubic centimeters of water. After shaking one day it was found that 0.0035 gram of K_2O, or 0.31 per cent of the total K_2O in the rock, had been extracted by the solution. A week later the potash in solution was found to be 0.61 per cent of the total K_2O originally in the rock. These facts are also of interest in relation to agricultural or soil chemistry and are probably to be explained as due to a metathetical reaction by which a part of the calcium of the gypsum in the solution exchanges itself for the potassium in the leucite.

In order to see if this exchange could be brought about to a greater extent by grinding the constituents 10 grams each of wyomingite and gypsum were ground with 50 cubic centimeters of water in an agate mortar by a mechanical grinder for two hours. The resulting solution, after filtration, was found to contain 2 per cent of all the potash (K_2O) in soluble form. This is, however, only 0.22 per cent of the rock.

An experiment similar to the last was carried out with lime in place of gypsum, resulting in the extraction of 2.64 per cent of the potash in soluble form, or 0.34 per cent of the rock.

EFFECT OF HEATING WYOMINGITE.

Merely heating wyomingite to a dull red apparently causes very little change in it. After it is heated a trace of its potash is found to be soluble in water, but this fact can have no commercial significance. For effective action some reagent must be added. The following notes describe the effect of heating mixtures of the rock and certain reagents:

EXPERIMENTS WITH GYPSUM.

In addition to the experiments with gypsum already described, the following were made:

1. A mixture of 1 gram of wyomingite and 0.2 gram of gypsum was finely ground and ignited until fused. After cooling it was ground and extracted with water. The soluble K_2O amounted to 1.8 per cent of the rock, or 16.2 per cent of the total K_2O.

2. A mixture of 1 gram of wyomingite, 0.22 gram of gypsum, and 0.10 gram of sodium chloride was finely ground, ignited to a dull red, and, after cooling, extracted with water. The soluble K_2O amounted to 2.5 per cent of the rock, or 22.4 per cent of the total K_2O.

In the light of these results gypsum does not appear to be very efficient in decomposing the rock, at least when used in the proportions tried in these experiments.

EXPERIMENTS WITH SULPHURIC ACID.

1. One gram of wyomingite was moistened with 1 cubic centimeter of concentrated sulphuric acid and heated gently in a large platinum crucible for about an hour until fumes came off freely. The soluble K_2O extracted amounted to 2.72 per cent of the rock, or 24.5 per cent of the total K_2O.

2. One gram of wyomingite was ground with 0.22 gram of gypsum, moistened with dilute sulphuric acid equivalent to 0.18 gram H_2SO_4, dried, and heated to redness. The soluble K_2O extracted amounted to 2.75 per cent of the rock, or 24.8 per cent of the total K_2O.

EXPERIMENT WITH POTASSIUM BISULPHATE.

On the theory that the action of hot sulphuric acid on wyomingite produces some potassium bisulphate, an experiment was made with potassium bisulphate itself as a reagent. One gram of wyomingite was finely ground with 0.5 gram of potassium bisulphate, and the mixture was brought up slowly to a dull-red heat. The result was disappointing. Hardly any more K_2O was extracted than had been added in the reagent, though nearly all the Na_2O of the wyomingite had been converted into a soluble form.

This experiment seems to indicate that the rearrangement effected in the sintering is governed by the law of mass action, and that treatment with a potassium reagent is not likely to be efficient, at least for a commercial process.

EXPERIMENTS WITH ALUNITE.

Notwithstanding the unfavorable result of the last experiment it seemed worth while to try the effect of heating wyomingite and alunite together. Alunite is to be found comparatively near the Leucite Hills, and the idea of the experiment was that a combination of the two rocks might be treated in a single process at a lower cost than the combined cost of treating each separately. The alunite used came from Marysvale, Utah, and was part of that analyzed by W. T. Schaller for Butler and Gale,[1] who described the deposit in 1912.

[1] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, 1912.

Composition of alunite.

[W. T. Schaller, analyst.]

Alumina (Al_2O_3)	37.18
Ferric oxide (Fe_2O_3)	Trace.
Sulphur trioxide (SO_3)	38.34
Phosphoric anhydride (P_2O_5)	.58
Potash (K_2O)	10.46
Soda (Na_2O)	.33
Water (H_2O)	12.99
Silica (SiO_2)	.22
	100.10

1. Wyomingite (0.2 gram) was finely ground with 0.2 gram of alunite. After being slowly heated to a dull red and then held at a medium red for an hour in a J. Lawrence Smith platinum crucible the cooled lump was extracted with water and yielded soluble K_2O equivalent to 6.15 per cent of the mixture. As the theoretical yield of K_2O would be 5 per cent from the alunite and 5.5 per cent from the wyomingite, a total of 10.5 per cent, the amount actually extracted was 57 per cent of the total K_2O—that is, the K_2O extracted might be considered all that in the alunite alone plus about 20 per cent of that in the wyomingite. As there is a very large quantity of wyomingite available and as the cost of mining and crushing would doubtless be low, it would appear that when alunite is being treated the addition of wyomingite might pay.

2. The next experiments consisted in varying the proportions of alunite and wyomingite. By taking 0.2 gram of alunite and 0.4 gram of wyomingite, the soluble K_2O obtained amounted to 7.6 per cent of the mixture. The theoretical yield of K_2O would be 3.5 per cent from the alunite and 7.4 per cent from the wyomingite, a total of 10.9 per cent; the K_2O extracted therefore amounted to 70 per cent of the total—that is, all the potash in the alunite was extracted and 55 per cent of that in the wyomingite.

3. In another experiment with 0.2 gram of alunite and 0.6 gram of wyomingite the yield in soluble K_2O was 3 per cent of the mixture. As the theoretical yield would be 2.6 per cent from the alunite and 8.2 per cent from the wyomingite, or 10.8 per cent in all, the result represents only 28 per cent of the total K_2O. In this experiment the wyomingite was only slightly attacked.

EXPERIMENT WITH CALCIUM CARBONATE.

The well-known method devised by J. Lawrence Smith for determining the alkalies in silicate rocks, involving the use of calcium carbonate and ammonium chloride, probably owes its success to the action of calcium chloride formed during the reaction. However that may be, the proportions of the reagents used in this method are too great to be practicable for commercial process, and accordingly it seemed desirable to make a few experiments to see if the proportions of the reagents could be reduced. One experiment was tried out with calcium carbonate alone, 0.3 gram of calcium carbonate to 1 gram of wyomingite being used. At the temperature employed, a dull-red heat, scarcely more than a trace of potash was rendered soluble. This result seemed to show that the chief attack in the Smith method is due to the calcium chloride, and accordingly the next experiments were made with calcium chloride alone.

EXPERIMENTS WITH CALCIUM CHLORIDE.

It was found that with moderate proportions of calcium chloride too high a heat, say 1,000° C., causes the mixture to vitrify so that extraction of the potash by water is impracticable. The temperature used was therefore limited to a dull-red heat. The calcium chloride was added in solution to finely ground wyomingite in a platinum crucible, and the mixture was slowly stirred during evaporation until the mass was dry.

The results of the experiments are summarized below:

Potash rendered soluble when wyomingite is heated to a dull red with calcium chloride.

Wyomingite.	$CaCl_2$.	K_2O rendered soluble.	
		Percentage of rock.	Percentage of total K_2O.
Gram.	*Gram.*		
1	0.2	3.03	27.3
1	.4	6.44	58.0
1	.6	8.10	73.0

EXPERIMENT WITH MAGNESIUM CHLORIDE.

One gram of powdered wyomingite was moistened with a saturated solution of magnesium chloride, dried, and heated slowly to dull redness in an open crucible. On extraction the soluble K_2O amounted to 3.22 per cent of the rock, or 29 per cent of the total K_2O in the rock.

EXPERIMENT WITH A BITTERN.

When it was found that a part of the alkalies in wyomingite is rendered soluble by heating with magnesium chloride, an experiment was made with a bittern, such as is obtained in the manufacture of salt at Great Salt Lake, having the composition shown below:

Composition of bittern used.

	Grams per liter.	Per cent of salts.
Magnesium (Mg)	24.9	7.76
Potassium (K)	15.9	4.94
Sodium (Na)	69.3	21.60
Sulphate (SO_4)	65.0	20.27
Chloride (Cl)	145.9	45.43
	321.0	100.00

One gram of wyomingite was drenched with 2 cubic centimeters of the bittern, dried, and heated to dull redness, with the following results: Soluble K_2O, 5.32 per cent of the dry mixture; theoretical yield of K_2O, 2.3 per cent from the bittern and 6.8 per cent from the wyomingite, or 9.1 per cent in all; K_2O extracted, 58 per cent of total K_2O. The K_2O extracted may be considered to be all that of the bittern used and 44 per cent of that in the wyomingite.

EXPERIMENT WITH AMMONIUM SULPHATE.

Ammonium chloride in excess and under pressure is known to react with leucite at 350° in such a way as to set potassium chloride free.[1] It seemed worth while to try ammonium sulphate also. In a single experiment 1 gram of wyomingite was heated over night in a closed glass tube at 310° with 0.2 gram of ammonium sulphate. The potash rendered soluble by this treatment amounted to 0.0352 gram, or 31.8 per cent of the total potash in the rock.

[1] Clarke, F. W., and Steiger, George, The action of ammonium chloride upon silicates: U. S. Geol. Survey Bull. 207, p. 16, 1902.

THE PHYSICAL CONDITIONS AND AGE INDICATED BY THE FLORA OF THE ALUM BLUFF FORMATION.

By Edward Wilber Berry.

INTRODUCTION.

The present paper has for its purpose the description of a small flora collected from the Alum Bluff formation, representing a horizon hitherto unrepresented paleobotanically in southeastern North America, and the discussion of the bearing of this flora on the physical conditions of deposition and the probable age of the deposits.

GEOLOGY OF THE DEPOSITS.

The Alum Bluff formation was named from the bluff of that name on the east bank of the Apalachicola River, about 25 miles below Chattahoochee or River Junction, in Liberty County, Fla.[1] (See Pl. VII, *B*, p. 56.) It is, according to present knowledge, the uppermost formation of the Apalachicola group. It comprises three members, which, named in ascending order, are the Chipola marl member, the Oak Grove sand member, and the Shoal River marl member.

The Chipola marl, which is a thin yellowish clay marl at the base of the formation as defined by Matson and Clapp, carries a very extensive and well-preserved marine fauna. It was named from Chipola River, in Calhoun County, Fla. The Oak Grove sand, stratigraphically intermediate between the Chipola and Shoal River, is a thin, highly fossiliferous gray or greenish fine sand named from Oak Grove, on Yellow River, and not represented by a lithologic unit at Alum Bluff. The Shoal River marl, the highest known fossiliferous member of the formation, is a thin series of interbedded greenish sands and marls overlying the Oak Grove sand. It was named from Shoal River, in western Florida, and is not represented by a lithologic unit at Alum Bluff.

The following section was taken at the point where the fossil plants were collected, near the lower end of the bluff and in the immediate vicinity of the section measured by Dall.[2] It is deemed worthy of reproduction because it differs in certain particulars from Dall's section. Still other sections from different parts of the bluff are given by Sellards and Gunter.[3]

Section at Alum Bluff, Fla.

	Feet.
Pleistocene (?):	
Light-colored ferruginous, rather loose sands.	9
Hard reddish clay	2
Variegated reddish and yellowish ferruginous sands	65
Miocene:	
Choctawhatchee marl:	
Dark-gray pyritiferous clay, more or less carbonaceous but scarcely meriting the term lignitic given to it by Langdon, as no lignite or plant fossils were observed in it. Traces of invertebrate fossils, for the most part undeterminable, were observed in places. The pyritiferous character of the clay gives it an alum-like taste, which accounts for the name of the bluff. Approximate thickness.	25
Bluish (when unweathered) fossiliferous clay marl of irregular thickness, carrying *Mulinia congesta*, *Ecphora quadricostata*, *Turritella variabilis*, and other species; much oxidized in its upper portion, in which the fossils are represented by poor casts, owing to the solution of the shell substance	15–30
Erosion unconformity.	

[1] The geology of this region is fully discussed in the following publications:

Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida: Florida Geol. Survey Second Ann. Rept., pp. 21-173, 1909.

Vaughan, T. W., A contribution to the geologic history of the Floridian Plateau: Carnegie Inst. Washington Pub. 133, pp. 99-185, 1910; see also U. S. Geol. Survey Prof. Paper 71, pp. 741-745, 1912.

[2] Dall, W. H., and Stanley-Brown, J., Cenozoic geology along the Apalachicola River: Geol. Soc. America Bull., vol. 5, p. 157, 1894

[3] Sellards, E. H., and Gunter, Herman, Florida Geol. Survey Second Ann. Rept., pp. 275, 276, 1909.

	Feet.
Oligocene:	
Alum Bluff formation:	
Cross-bedded laminated sands with clay laminæ and thin distorted clay lenses of small extent. The sands are locally thicker bedded and argillaceous, especially in the upper part, where they are in places packed with the distorted detached rays of a Sabal-like palm. In the lower part they are more evenly bedded and less argillaceous, being composed largely of a somewhat coarser gray iron-stained sand with vegetable matter aggregated in definite but not everywhere horizontal layers. Here and there are thin iron crusts, and some of the more argillaceous laminæ are bluish in color. Leaf impressions are much more abundant and varied in these lower layers. The thickness is variable, the maximum observed being about	10
Gray calcareous compact massive, in places slightly phosphatic sand, somewhat fossiliferous; thickness about	12
Chipola marl member: Compact ferruginous, abundantly fossiliferous argillaceous sand carrying Orthaulax and other characteristic Oligocene invertebrates; thickness exposed	3–4

most Oligocene or basal Miocene flora, practically the only one known in North America.

In Forrest County, Miss., in beds included by L. C. Johnson in the Hattiesburg clay (see Pl. VII, *A*, p. 56), I discovered in the summer of 1910 a small flora that appears to be synchronous with that at Alum Bluff. The exact locality is on the south side of the New Orleans, Mobile & Chicago Railroad, 1 mile east of Raglan, and the outcrop shows the following section (see also fig. 8):

Section near Raglan, Miss.

	Feet.
1. Compact reddish argillaceous sand	0–12
2. Light sandy clay	1–2
3. Compact argillaceous lignite or brown lignitic clay	2
Unconformity (local?).	
4. Yellowish or gray argillaceous fine sand or sandy clay, grading into underlying beds	10
5. Similar materials of greenish color, weathering yellowish, irregularly bedded and carrying large numbers of poorly preserved plant remains, mostly palm rays; grades into underlying beds; thickness about	4
6. Yellowish or greenish much-jointed sandy clay	6

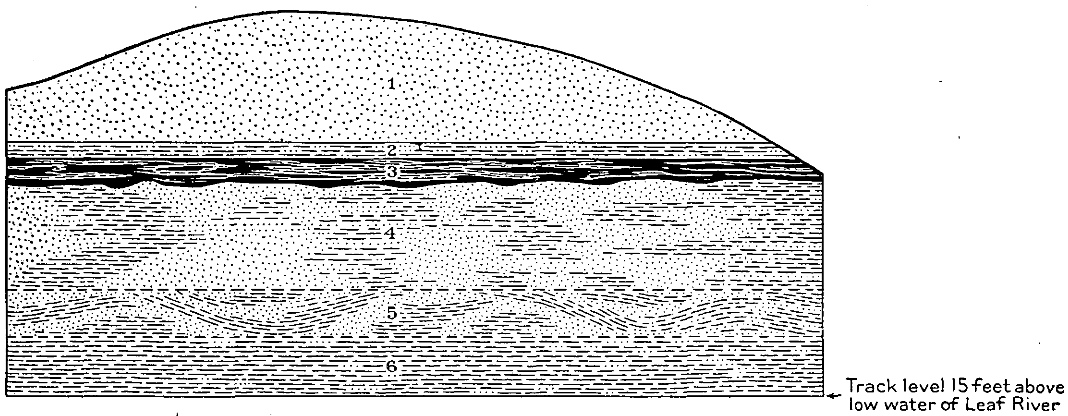


FIGURE 8.—Section of Hattiesburg clay near Raglan, Miss. Numbers correspond to those given in the section in the text.

Alum Bluff is a most interesting spot to the physiographer, because of the striking contrast in topography between the east and west banks of the river; to the geologist, because it is a classic locality for the so-called Old Miocene and represents also the oldest known southern outcrop of the Chesapeake Miocene; and to the botanist, because in the wooded and damp ravines along the bluff are to be found two isolated gymnosperms, both relics of bygone floras, *Taxus floridana* Nuttall and *Tumion taxifolium* (Arnott) Greene. Alum Bluff is of particular interest to the paleobotanist, because it furnishes a representation of an upper-

The plants in the sands at both the localities mentioned above are few and very friable. Collections could not be made in the usual way, and as my improvised method proved very satisfactory it is worth describing. A small excavation in the loose, slumped sand was lined with a large piece of burlap. This was partly filled with plaster. While the plaster was still soft the sandy specimen was placed in it, the face of the specimen being left about on the level of the plaster. After the plaster had set the face was thickly covered with cotton, over which the free ends of the burlap were wrapped and tied firmly. Every specimen treated in this way, some of which were 10 inches in diameter, survived the rough handling on the river boat and the freight transportation to Baltimore.

Fossil plants from Alum Bluff have been mentioned by Langdon,[1] Foerste,[2] and Dall.[3] A few fragments of Sabalites were collected by Dall, but no systematic collections were made until I visited this outcrop in 1910 in company with E. H. Sellards, State geologist of Florida.

CHARACTER OF THE FLORA.

The flora is limited to 13 described species, although fragments of other species are present, and I observed but did not succeed in collecting a palmately veined Ficus, leaves of Gyminda or Xanthoxylum, and pods resembling those of the existing *Gleditsia aquatica* Marsh.

The determined species comprise a spot fungus (Pestalozzites), a very abundant fan palm (Sabalites), and 11 species of dicotyledons, including an elm, breadfruit, buckthorn, camphor, satinwood, ironwood, and persimmon. There are 11 genera in 9 families and 8 orders. These families are the elm (Ulmaceæ), mulberry (Moraceæ), pisonia (Nyctaginaceæ), senna (Cæsalpiniaceæ), rue (Rutaceæ), buckthorn (Rhamnaceæ), laurel (Lauraceæ), sapodilla (Sapotaceæ), and ebony (Ebenaceæ). The families Lauraceæ and Sapotaceæ are each represented by two species; the remaining seven families have each a single species. By far the most abundant form is the palm, broken stipes and detached rays of which are thickly crowded in the sands in places. Four of the plants are ordinarily considered strictly tropical—the breadfruit (Artocarpus), brasiletto (Cæsalpinia), Nectandra, and satinwood (Fagara). The genera Pisonia and Cinnamomum are commonly considered tropical, but Pisonia reaches the keys of southern Florida in the existing flora and the camphor tree (Cinnamomum) ranges northward to southern Japan and to the rain forests of southwestern China, while *Cinnamomum camphora* Linné is hardy in cultivation around Tallahassee, Fla., and is not uncommon as an escape from cultivation in woods and thickets throughout peninsular Florida, being freely seeded by birds. In fact, soil, humidity, and the length of the growing season seem to govern the extension of the tropical flora into the temperate zones to a much greater extent than actual extreme temperatures, the existing floras of both southeastern Asia and southeastern North America showing many parallel examples of such extensions.

The Sabalites is represented in the existing flora by the genus Sabal Adanson, which is now confined to America. It consists of eight coastal or stream-border shrubs and trees, five of which are confined to the West Indies, Mexico, and Venezuela; one is confined to peninsular Florida, and two range northward along the Atlantic coast to the Carolinas.

The large mass of frayed and tangled rays and stipes of Sabalites in a matrix of sandy alluvium both at Raglan, Miss., and Alum Bluff, Fla., suggest that at the time these deposits were laid down the shores were low and were densely clothed with palmetto "swamps" or brakes.

The genus Ulmus, although it has tropical allies, is in the existing flora a strictly north-temperate form having about 16 widely distributed species.

The family Rhamnaceæ is mostly tropical, but several of the genera extend into the Temperate Zone, and Rhamnus, in particular, is mostly extratropical in the North Temperate Zone. There are about 75 existing species, and of the dozen North American forms several range northward to Canada and British America and only 1 ranges as far south as Florida.

The genus Bumelia has about a score or more of existing species, ranging from Brazil northward through Central America and the West Indies to the United States, where two species are found as far north as Virginia and Illinois.

The genus Diospyros belongs to a large family that is mostly tropical in its distribution. Of the more than 200 existing species our common *Diospyros virginiana* Linné is found as far north as southern New York and New England. The genus is represented in southern Europe, and there are several species in eastern Asia. Moreover, of the 100 or more

[1] Langdon, D. W., Some Florida Miocene: Am. Jour. Sci., 3d ser., vol. 38, p. 322, 1889; Geology of the Coastal Plain of Alabama, p. 373, 1894.
[2] Foerste, A. F., Studies on the Chipola Miocene of Bainbridge, Ga., and of Alum Bluff, Fla.: Am. Jour. Sci., 3d ser., vol. 46, pp. 244–254, 1893; Fossil palmettos in Florida: Bot. Gaz., vol. 19, p. 37, 1894.
[3] Dall, W. H., and Stanley-Brown, Joseph, Cenozoic geology along the Apalachicola River: Geol. Soc. America Bull., vol. 5, pp. 147–170, 1894.

fossil species that have been described many occur in associations that are obviously temperate in character.

To summarize the climatic conditions indicated by the flora, they are those of a tropical flora becoming replaced by a temperate flora, namely, subtropical or very warm temperate. These conditions are obviously different from those indicated by the Chipola marine fauna, which comprises over 400 known species, mostly Mollusca, and indicates a shallow sea (maximum depth not over 20 fathoms) and, according to Vaughan,[1] strictly tropical temperatures—that is, the bottom temperature of the water did not go below 70° F. during the year.

As has already been indicated, the flora embraces a number of tropical types which, as is shown by the existing flora, are legitimately to be expected to extend more or less beyond the equatorial belt in areas where rainfall is abundant and where extremes of low temperature are absent. Associated with these are forms like Ulmus, whose modern representatives are prevailingly north temperate but some of which extend into boreal regions. Still other of the Alum Bluff forms, the Rhamnus, Bumelia, and Diospyros, represent families which are mainly tropical in the existing flora but which as represented by these genera have extended over large areas of the warmer parts of the Temperate Zone.

It seems to me that among existing plant assemblages the Alum Bluff flora represents three types of plant associations. One corresponds in a general way to the "low hammock" of present-day peninsular Florida, a type intermediate between the true hammock and the swamp type. A second plant assemblage indicated is that of the low-lying semiswamp palmetto-brake type, along with some forms of the sandy strand, such as Pisonia, Cæsalpinia, and Fagara. In other words, this flora would find a congenial habitat at the present time in the delta of Apalachicola River or almost anywhere along the coast of peninsular Florida. Although so much less extensive, the Alum Bluff flora is somewhat less tropical in its facies than the flora of the Wilcox group and decidedly less tropical than the floras of the Claiborne, Jackson, Vicksburg, or Catahoula. On the other hand, it has not nearly the temperate facies of the flora of the overlying Chesapeake Miocene and also indicates much more humid conditions than the latter. This statement is based on the flora of the Calvert and a consideration of the abundant marine faunas of the Calvert, St. Marys, Yorktown, Duplin, Choctawhatchee, and Jacksonville formations.

[1] Vaughan, T. W., Carnegie Inst. Washington Pub. 133, p. 156, 1910.

The Alum Bluff flora may be considered to be the result of a reversal of the history of the present flora of peninsular Florida. That is to say, the present flora represents primarily a temperate flora receiving additions from the Tropics, whereas the Alum Bluff flora represents an endemic tropical flora gradually becoming invaded by members of a temperate flora as a result of changing climatic conditions.

AGE OF THE FLORA.

The stratigraphic relations clearly indicate that the Alum Bluff flora is younger than the Vicksburg Oligocene and older than the Chesapeake Miocene. The faunal and floral evidence is equally conclusive. Not a single Alum Bluff plant is common to the Oligocene (Vicksburg and Catahoula) floras of Mississippi, Louisiana, and Texas nor to the Chesapeake Miocene floras, which are, however, smaller than those from the Oligocene. Moreover, the facies of the Alum Bluff flora is decidedly different from that of the floras of any of these horizons. There are no western United States or West Indian fossil floras for comparison, so that it remains to consider the probable European equivalents of the Alum Bluff.

As the Alum Bluff flora is obviously younger than the abundant European floras of the Sannoisian (Lattorfian, Tongrian) and Stampian (Rupelian) and older than the exceedingly rich floras of the Helvetian and Tortonian (Vindobonian), the only stages remaining are the Chattian (Kasselian), Aquitanian, and Burdigalian (Langhian, Mayencian).

The Chattian (Fuchs, 1894) is the lower Aquitanian of Munier Chalmas and De Lapparent (1893). It is considered the equivalent of the Kasselian and in the Paris Basin is represented, according to Lemoine, by the meulières de Montmorency. According to Haug its invertebrate fauna is distinguished by the absence of Miocene types.

The Aquitanian (Mayer, 1857) now has the narrow limits assigned by Dollfus (1906–7). It marks the maximum regression of the Oligocene sea due to the elevation of the Pyrenees and the beginning of Alpine orogenesis. Marine waters invaded the marginal coasts in Aquitaine, the Gironde, and Provence, in southern Spain, in Italy, and at various points on the south side of the eastern Alps; but the great bulk of the Aquitanian sediments are those of lakes, swamps, and lagoons, with lignites and abundant and widespread mammals and plants. In Aquitaine the Tongrian is said to grade imperceptibly into the Aquitanian both lithologically and faunally, and the latter passes into the Burdigalian in the same gradual manner. The floras of the Aquitanian are likewise transitional in character between Oligocene and Miocene. The marine faunas, however, are said by Haug to contain only 4 per cent of Oligocene species and many Miocene species, but the foraminiferal genus Lepidocyclina passes without modification from the Chattian into the Aquitanian. The Aquitanian has long been considered the uppermost stage of the Oligocene, although many paleontologists have pointed out the resemblances between the upper Aquitanian floras and faunas and those of the Burdigalian. In recent years, under the leadership of Dollfus and other French students, the Aquitanian has been made the basal stage of the Miocene, although the question of its reference to the Oligocene or Miocene is vigorously disputed.

The Burdigalian (Depéret, 1892) is closely related to the Aquitanian both faunally and florally. The marine faunas as well as the terrestrial floras are said to indicate a slight lowering of temperatures since Aquitanian time. Tectonic changes had caused the disappearance of the broad lakes of the Aquitanian, and the Burdigalian materials comprise marine sediments on the southern and western borders of the continent and a series of river, flood-plain, and swamp deposits (brown coal) in the region extending from France to Bohemia.

It can not be said that the Alum Bluff flora offers conclusive evidence for detailed correlation, as it is too small. All but two of the species are new and offer only indirect evidence. Of these new species the Ulmus is very similar to *Ulmus longifolia* Unger, of the Aquitanian of Bohemia, Germany, Styria, and France, and the Sapotacites is most like *Sapotacites* (*Chrysophyllum*) *sagorianum*, from the Aquitanian of Sagor, in Carniola, described by Ettingshausen. The two species with an outside distribution, *Cinnamomum scheuchzeri* and *Diospyros brachysepala*, have both been identified in beds from a great variety of horizons in Europe. Although many of these identifications are of doubtful value, both species had a wide range, geographic as well as geologic. The original descriptions of both, by Alexander Braun, were based on material from the Tortonian of Oeningen in Baden. The two species are typically Oligocene-Miocene forms and both are common and characteristic in the Aquitanian and Burdigalian of Europe.

It is thus apparent that the Alum Bluff flora can be considered either Aquitanian or Burdigalian, with a slight preponderance of the evidence in favor of the Aquitanian. Maury [1] on the evidence of the molluscan fauna correlated the Chipola marl with the Aquitanian and considered the Oak Grove fauna, as well as that of the sands at Alum Bluff above the Chipola, as "transitional" between Aquitanian and Miocene. If subsequent paleozoologic studies corroborate Maury's work, there will be substantial agreement between the floral and faunal evidence.

If the Alum Bluff formation is of Aquitanian or Burdigalian age—and one or the other alternative seems certain—the more or less academic question is raised whether it shall be classed as Oligocene or Miocene.

Since the proposal of the term Oligocene by Beyrich in 1854 many have questioned its utility or ultimate survival. Certainly there is but slight structural (diastrophic) evidence for placing the Oligocene-Miocene boundary in Europe between the Aquitanian and Burdigalian, and the marine faunas as well as the terrestrial floras and faunas show a gradual transition from the one stage to the other, so that the French paleontologists will probably be followed in their contention that the Aquitanian should be placed in the Miocene.

In considering the American application of the term Oligocene, it may be noted that there appears to have been continuous and uninterrupted sedimentation in the Florida area from the deposition of the underlying Chattahoochee formation into Alum Bluff time. There also seems to have been a succession of minor earth movements during this period, and there was a greater influx of terrigenous materials into

[1] Maury, C. G., Bull. Am. Paleontology No. 15, 1902.

the Alum Bluff sea than into the Chattahoochee sea, a change in sedimentary character more probably due to an inland rise of the land which accelerated erosion than to the shallowing of the sea.

It seems obvious that the Alum Bluff formation as a whole is a predominantly shallow-water deposit of clays and sands and that the Chipola, Oak Grove, and Shoal River members are faunal zones contained in successive lenticular beds in the clays or sands. The faunules of these zones are closely related but show, according to Dall,[1] certain elements of transition in the Oak Grove sand from the tropical Chipola fauna to one indicating a slight lowering of the temperature.

There is thus no structural (diastrophic) evidence for drawing the Oligocene-Miocene boundary between the Chattahoochee and Alum Bluff formations, nor is there any floral or faunal evidence for such a boundary. There is such a break between the Vicksburg and Apalachicola groups, and the Alum Bluff is separated by an erosion unconformity from the overlying Choctawhatchee Miocene. It rests with invertebrate paleontology to determine whether or not the whole of the Apalachicola group shall be considered Miocene. Whatever may be the final verdict, it remains true that the flora preserved at Alum Bluff records the last phase of sedimentation before the area emerged from the sea and that the most profound break in Tertiary sedimentation in the southeastern United States, emphasized equally by epeirogenic, faunal, and floral changes, was at the end of Apalachicola time—that is, it is represented by the unconformity at the top of the Alum Bluff formation.

SYSTEMATIC ACCOUNT OF THE FLORA.

Class FUNGI.

Order MELANCONIALES.

Family MELANCONIACEÆ.

Genus PESTALOZZITES Berry.

Pestalozzites sabalana Berry, n. sp.

Plate VIII, figure 3; Plate IX, figure 9.

Essential characters unknown. Found infesting the leaves of *Sabalites apalachicolensis* Berry in considerable abundance and causing the formation of leaf spots. These spots are of definite form and regular outline, small and circular at first, becoming larger with age and elongated parallel to the long axis of the ray, thus becoming elliptical or lenticular in outline. Maximum size observed, 1.5 centimeters in length and 0.5 centimeter in width. Average size, about 6 by 2 millimeters. The appearance of the infested leaves is well illustrated in the figures, and they are scarcely to be distinguished from numerous leaves of the existing scrub palmettos, as for example, *Serenoa serrulata* (Michaux) Hooker, infested with the existing leaf-spot fungus Pestalozzia sp.

Occurrence: Hattiesburg clay, Raglan, Forrest County, Miss.; collected by E. W. Berry. Alum Bluff formation, Alum Bluff, Liberty County, Fla.; collected by E. W. Berry.

Collections: United States National Museum.

Class ANGIOSPERMÆ.

Subclass MONOCOTYLEDONÆ.

Order ARECALES.

Family PALMACEÆ.

Genus SABALITES Saporta.

Sabalites apalachicolensis Berry, n. sp.

Plate VIII, figures 1–5; Plate IX, figure 9.

Leaves of variable size, the maximum diameter estimated (from collected material) at about 120 centimeters. Rachis large, linear, not enlarged at the base of the leaf, lenticular in cross section, with straight unarmed edges, continued for a short distance on the lower side of the leaf as a rapidly narrowed acumen which is only 3.5 centimeters in length in the small specimen figured; abruptly rounded-truncate at the base of the leaf on the upper side, where an inconspicuous ligule is present. Rays numerous, 40 to 60 in number, carinate, linear-lanceolate in form, expanding to their middle, and free for about the upper third of their length, more or less curved at the base. Maximum width observed about 4 centimeters; average about 2 centimeters. Midribs of rays not especially strong or prominent. Secondaries numerous, fine, longitudinal, parallel, largely immersed in the leaf substance, which must have been coriaceous. No transverse veinlets observed.

This species has a recorded range along the coast of the Gulf of Mexico from Florida to

[1] Dall, W. H., Contributions to the Tertiary fauna of Florida: Wagner Free Inst. Sci. Trans., vol. 3, pt. 2, pp. 1574–1575, 1903.

central Mississippi and is in places abundant but everywhere fragmentary. In the absence of fairly well preserved specimens showing the rachis and acumen it is impossible to distinguish this form from the Wilcox species *Sabalites grayanus* Berry or the Oligocene species *Sabalites vicksburgensis* Berry, so that possibly the latter species, represented by incomplete material, may be present in the Alum Bluff sands, although I consider this extremely doubtful.

Sabalites grayanus differs from the present species in the expanded upper end of the rachis, the longer and more gradually narrowed acumen, and the more numerous rays, which are usually more conspicuously veined.

The fragments of rays which are so common in some of the deposits of the Vicksburg group and which are made the basis of *Sabalites vicksburgensis* are to be distinguished from *S. apalachicolensis* chiefly by their much more prominent venation and longer and more slender acumen. The present species at its region of maximum occurrence at Alum Bluff is badly infested with a leaf-spot fungus which I have described as *Pestalozzites sabalana* Berry, n. sp.

The foliage of palms is abundant and well distributed throughout the deposits of the Wilcox, Claiborne, Vicksburg, and Apalachicola groups, indicating the abundance of plants of this type in southeastern North America during the Tertiary period. Few of these remains represent entire leaves, and in many places only fragments of rays are preserved. Palm leaves are notoriously difficult of determination, and the bulk of remains representing flabellate fan palms with an acumen are referred by American students to the genus Sabalites and by European students to Sabal. Two methods of specific differentiation are possible. Minor differences and stratigraphic position may be ignored, as in the case of the geographically and geologically wide-ranging *Sabal major* Unger of Eurasia, or minor differences that also represent differences in geologic age may have considerable weight in specific differentiation. The latter is the method that I have found most useful from both the biologic and the geologic viewpoint.

The extreme tropical climate of Vicksburg and Catahoula time, which is reflected in the abundant traces of palms found in deposits of Vicksburg or Catahoula age from Texas eastward, continued through the time of deposition of the Chipola marl member of the Alum Bluff formation. Fortunately conditions were favorable for petrification, and fragments of petrified palm trunks, many of them of large size, are abundant throughout the area underlain by the Vicksburg or Catahoula deposits. Seven species of Palmoxylon have been described from these deposits. So far as I am aware no petrified palms have thus far been obtained from the Alum Bluff sands, but palm foliage is very abundant in the leaf-bearing lens at Alum Bluff. I have never seen so great an abundance of stipes and rays of palms as occur at this outcrop. In places whole layers consist of a mass of frayed and tangled rays in a matrix of sandy alluvium. They are usually much macerated, and only here and there can larger fragments of leaves be found. They are almost equally abundant in the similar materials cropping out near Raglan, Miss. This suggests the presence near the coast in late Alum Bluff time of extensive palmetto swamps or brakes along the lower reaches of a sluggish river or estuary only a few feet above mean water level—not flooded or true swamps, but subject to periodic overflow.

Occurrence: Hattiesburg clay, Raglan, Forrest County, Miss. (common; collected by E. W. Berry); and near Chicoria, on Chickasawhay River, Wayne County, Miss. (collected by E. W. Berry). Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry), and Boynton Bluff, Choctawhatchee River, Fla. (collected by E. H. Sellards).

Collections: United States National Museum.

Subclass DICOTYLEDONÆ.

Order FAGALES.

Family ULMACEÆ.

Genus ULMUS Linné.

Ulmus floridana Berry, n. sp.

Plate IX, figures 5–7.

Leaves of medium or small size, ovate-lanceolate in general outline, with slightly inequilateral cuneate rounded or subcordate base, and a gradually narrowed, somewhat extended acuminate tip. Length from 4 to 7 centimeters. Maximum width, in the basal half of the leaf, from 1.5 to 3 centimeters. Margins entire at the extreme base, above which they are finely and sharply doubly serrate, the teeth increasing slightly in size distad. Petiole short and stout, about 2.5 millimeters in length. Midrib of medium size, relatively thin and flexuous. Secondaries thin, 10 to 12, subopposite to alternate, in rather irregularly spaced pairs; they diverge from the midrib at angles varying from about 75° near the base to 30° near the tip, averaging about 50°; they pursue a rather straight craspedodrome course and near their tips give off one or two outwardly directed tertiaries, which run to the teeth or to the sinuses.

This well-marked species of Ulmus appears to have been common during Alum Bluff time and constitutes the one strictly temperate element in the Alum Bluff flora. Among existing species it is most similar to *Ulmus alata* Michaux, which ranges from western Florida northward to Virginia and from Texas to Illinois. Like *U. alata*, the fossil species was probably an inhabitant of rich alluvial swamp and stream borders, for it seems probable that the fossiliferous lens in the Alum Bluff sands is the result of stream action. Among fossil species, of which many have been described, it bears more or less resemblance to a number of widely scattered forms, especially because the limits of variation of the foliage among different species of Ulmus are not wide. The most similar fossil form is *Ulmus longifolia*, described by Unger [1] and subsequently recorded from the Aquitanian of Bohemia, Germany, Styria, and France, which is extremely close to the American species.

The genus Ulmus may be distinguished from the allied genus Carpinus by the usually more inequilateral leaves and by the tertiaries to the marginal sinuses.

Occurrence: Hattiesburg clay, Raglan, Forrest County, Miss. (collected by E. W. Berry). Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Order **URTICALES**.

Family **MORACEÆ**.

Genus **ARTOCARPUS** Förster.

Artocarpus lessigiana floridana Berry, n. var.

Plate X, figures 5–7.

Leaves of large size, rather smaller than the type, but very poorly preserved in the current-bedded sands. At least 25 centimeters in length and about 13 centimeters in maximum width, thus more narrowly oblong in general outline than the type. Pinnately 8 to 10 lobed; the lobes short, relatively broad and conical, acutely pointed and directed obliquely outward, separated by very narrow sinuses. Midrib stout. Lateral primaries stout, diverging from the midrib at angles of about 45°, one to each lobe, terminating in its tip. Secondaries alternating with the primaries, one to each sinus, the latter with the characteristic marginal hem. Tertiaries mostly obsolete. Areolation quadrangular where seen. Texture coriaceous. There was evidently considerable variation in outline, for the basal portion of the leaf shown in figure 6 has a cuneate base and must have had strongly ascending lobes.

This form is based on very fragmentary specimens from the Alum Bluff sands. It may be distinguished from *Artocarpus lessigiana* by its relatively narrower form and its finer venation. The latter comes from the Wilcox group, a much earlier horizon, and has not been found in the intervening interval, represented by the Claiborne, Jackson, Vicksburg, and Catahoula deposits. I have a feeling that the Alum Bluff material represents a new species, but I hesitate to set up a species on such fragmentary material, which is, however, the best obtainable by the most careful collecting.

Remains of Artocarpus have been found in Europe, Greenland, and the United States. In this country we have the Laramie-Denver type, which is considered the parent stock of the present variety. This type and two other species are represented in the late Wilcox of Louisiana and Arkansas by excellent material. There is a Fort Union species and another Eocene form on the Pacific coast. In Europe several species range from the Upper Cretaceous to the Pliocene.

There are about 40 existing species of Artocarpus, all endemic in the southeastern Asiatic region, ranging from Ceylon throughout Malaysia to China and represented by cultivated forms in all tropical countries. They apparently did not become extinct in North America until the interval between the deposition of the Alum Bluff formation and the migration of the Chesapeake Miocene fauna into the Florida region, a migration indicating a lowering of

[1] Unger, Franz, Chloris protogæa, p. 101, pl. 26, fig. 5, 1847.

temperatures entirely sufficient to explain the extinction of Artocarpus on the mainland, but not offering a satisfactory explanation of its failure to survive in more southern latitudes.

Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Order CHENOPODIALES.

Family NYCTAGINACEÆ.

Genus PISONIA Linné.

Pisonia apalachicolensis Berry, n. sp.

Plate X, figure 1.

Leaves of relatively large size for this genus, obovate in general outline, with a broad apex, which is evenly rounded or bluntly pointed, and a gradually narrowed, sharply cuneate base. Length about 5.75 centimeters; maximum width, above the middle, about 2.4 centimeters. Margins entire. Texture coriaceous. Petiole short and stout, about 6 millimeters in length. Midrib stout but immersed in the thick leaf substance, curved. Secondaries entirely immersed and obsolete.

The modern species of Pisonia are numerous; they occur chiefly in the Tropics in both hemispheres and are largely coastal types. They are abundantly developed in Central America and tropical South America, and several species occur in the West Indies and Antilles. About 15 fossil species have been described, the earliest recorded being from the Upper Cretaceous of both America and Europe. The lower Eocene of southeastern North America has furnished two well-marked species, there is a species said to be represented by both leaves and fruit in the basal Eocene of the Rocky Mountain area, a fourth species occurs in the Claiborne group, and a fifth has been found in the Jackson. Perhaps the most similar fossil form, based on both leaves and fruits, is *Pisonia eocenica* Ettingshausen,[1] from the lignites of Haering, in Tyrol, which is upper Eocene or lower Oligocene in age, occurring also as early as the Lutetian of England.

Among existing species several are close to the present form. *Pisonia longifolia* Sargent, of the beaches and shores of lagoons from the Florida keys through the West Indies to Brazil, is very similar to *Pisonia apalachicolensis*, though only about two-thirds as large.

Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Order ROSALES.

Family CÆSALPINIACEÆ.

Genus CÆSALPINIA Linné.

Cæsalpinia sellardsi Berry, n. sp.

Plate IX, figures 1, 2.

Leaflets small, sessile, inequilateral, elliptical in outline, 7.5 millimeters in length and 4.2 millimeters in greatest width. Apex broadly rounded. Base strongly inequilaterally truncated, one margin ascending and the opposite margin subauriculate. Midrib slender. Secondaries two or more, slender, ascending, camptodrome. Margins entire.

This species, which is obviously new, is clearly the leaf of some shrub or tree of the family Cæsalpiniaceæ. Though only a few specimens were observed, this can not be considered as indicating scarcity, for the plant material at Alum Bluff is all rather meager and poorly preserved. It seems probable that the present species was a member of the strand flora, the strand being the habitat preferred by a number of species of this genus in the modern tropical American flora.

The fossil species may be compared with a number of existing species, with which it shows a very close agreement. Among previously described fossil species it is very close to what has been identified by Schenk[2] as *Cæsalpinia townshendi* Heer, from the Stampian of Sieblos, originally described by Heer[3] from the Aquitanian and Tortonian of Switzerland and Baden and identified by Geyler from the Messinian of Sicily.

There is a very notable display of Mimosaceæ and Cæsalpiniaceæ in the flora of the Wilcox group, and these elements probably continued to be prominent throughout the remainder of the Eocene and the Oligocene,

[1] Ettingshausen, Constantin, Die tertiäre Flora von Häring in Tirol, p. 43, pl. 11, figs. 1-22, 1853.

[2] Schenk, August, in Zittel, K. A., Handbuch der Palaeontologie, Abth. 2, Palaeophytologie, p. 700, fig. 369 (4), 1890.

[3] Heer, Oswald, Flora tertiaria Helvetiæ, vol. 3, pl. 137, figs. 26-37, 1859.

although the record is much less completely preserved in the post-Wilcox sediments. The present species is probably but one of many related forms that inhabited southeastern North America during the deposition of the Alum Bluff formation. It is more inequilateral than any of the known Tertiary species from this general region, although it might perhaps be considered a descendant of *Cæsalpinites pinsonensis* Berry, a somewhat smaller, less oblique, and more coriaceous form, from the sands of middle Wilcox age in Madison County, Tenn. It is named for Dr. E. H. Sellards, State geologist of Florida, who visited this celebrated locality with me and helped collect the fossil plants.

Occurrence: Alum Bluff formation, Alum Bluff, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Order GERANIALES.

Family RUTACEÆ.

Genus FAGARA Linné.

Fagara apalachicolensis Berry, n. sp.

Plate IX, figure 2.

Leaves compound. Leaflets sessile, of medium size for this genus, elliptical in general outline, with a broadly rounded apex and a broadly pointed base. Length about 3 centimeters; maximum width, above the middle, about 1.75 centimeters. Margins entire. Texture coriaceous. Midrib stout, somewhat flexuous. Secondaries four or five, subopposite to alternate pairs, irregularly spaced, diverging from the midrib at angles varying from 35° to 50°, rather straight in their courses, abruptly camptodrome close to the margins. Tertiaries thin, more or less immersed, forming small quadrangular or polygonal meshes.

The genus Fagara, which contains more than 150 living species of shrubs and trees, is cosmopolitan in tropical and subtropical countries. A few forms more properly referable to Xanthoxylum range for considerable distances in the Temperate Zone, particularly in southeastern North America. Fossil forms based on foliage are usually confused with the closely allied genus Xanthoxylum Linné. Leaflets referable to Fagara are not uncommon throughout our southern Tertiary deposits, several different forms from the Eocene and Oligocene having been described. The genus appears to have been especially prominent in the torrid flora of the Vicksburg group, and the leaflets are very abundant in the clays of that age. The present species is clearly unlike any of these, being especially different in its broad apex and narrowed base, and might readily be confused with the small entire leaves of some live oak. The scarcity of leaf remains in the Alum Bluff formation renders any remarks on the relative abundance of their described flora without much significance.

Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry), and Boynton Bluff, Choctawhatchee River, Fla. (collected by E. H. Sellards).

Collection: United States National Museum.

Order RHAMNALES.

Family RHAMNACEÆ.

Genus RHAMNUS Linné.

Rhamnus apalachicolensis Berry, n. sp.

Plate IX, figure 8.

Leaves rather large for this genus, broadly elliptical in general outline, with a broad and evenly rounded apex and base. Length about 8 centimeters; maximum width, in the middle part of the leaf, about 4.6 centimeters. Margins entire, evenly rounded. Texture subcoriaceous. Midrib stout. Secondaries stout, four or five alternate pairs, diverging from the midrib at angles of about 55° to 60°, curving upward almost immediately in a broad, sweeping curve, becoming subparallel with the lateral margins, along which they arch camptodromely. Tertiaries thin, closely set, subparallel, mostly percurrent at right angles to the midrib.

This large leaf is distinct from the numerous fossil species of Rhamnus previously described, although it resembles a number of them more or less closely. The genus has about 60 existing species, widely distributed in nearly all temperate and many tropical parts of the world and found on all the continents except Australia.

The genus Rhamnus is fairly prominent in Tertiary floras of southeastern North America, the Rhamnaceæ being also represented by forms of Zizyphus and Paliurus of tropical type. Six species from the Wilcox group have been described, but none are yet known from the Claiborne, Jackson, Vicksburg, or Catahoula.

Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Order THYMELEALES.

Family LAURACEÆ.

Genus NECTANDRA Roland.

Nectandra apalachicolensis Berry, n. sp.

Plate IX, figure 3.

Leaves oblong-ovate in general outline, broadest near the middle and tapering to the bluntly pointed apex and base. Length about 8 centimeters; maximum width, halfway between the apex and the base, about 2.5 centimeters. Margins entire, evenly curved. Texture coriaceous. Midrib stout. Secondaries about 10 subopposite pairs, diverging from the midrib at wide angles, about 60°, rather straight in their courses two-thirds of the distance to the margins, where they curve abruptly upward and form a succession of small camptodrome arches along the margins. Tertiaries obsolete.

The genus Nectandra has about 70 existing species confined to tropical and subtropical America, several of which are practically identical with this Alum Bluff species. There are numerous fossil species, the genus being well represented throughout the Eocene of southeastern North America, especially in the sediments of the Wilcox group, from which at least five species are known. It is represented in the Claiborne and Jackson but has not yet been found in the Vicksburg or Catahoula. The present species is not particularly close to any of the described fossil forms.

Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Genus CINNAMOMUM Blume.

Cinnamomum scheuchzeri Heer.

Plate X, figure 4.

Cinnamomum scheuchzeri. Heer, Flora tertiaria Helvetiæ, vol. 2, p. 85, pl. 91, figs. 4–22; pl. 92; pl. 93, figs. 1, 5, 1856.

This species was described by Alexander Braun from both calyx and leaves, obtained in the Tortonian of Oeningen, Baden. Typical material is common in the type area in both the Aquitanian and the Burdigalian. Only the original description of Heer, which is accompanied by ample figures, is cited above, for sanguine students have fancied that they had found this species at all horizons from the Upper Cretaceous to the Pliocene, and at a very large number of localities throughout the Northern Hemisphere. Some of these identifications are undoubtedly correct, and the species certainly had a wide geographic and geologic range. Other identifications are unquestionably erroneous, but it is impossible to sift the good from the bad without access to the original material, and I have therefore not attempted to give the synonymy or range.

The Alum Bluff material appears to be identical with a part of Heer's material from the type area, and it is also of the same age, so that I have no hesitation in identifying it with Heer's species. It denotes an ovate-lanceolate leaf, rather abruptly pointed at the extremities, the base being broader than the apex. Length about 8 centimeters; maximum width, in the middle part of the leaf, 2.7 centimeters. Margins entire. Texture coriaceous. Midrib stout. Lateral primaries one on each side, subopposite, suprabasilar, camptodrome. Secondaries thin, three or four camptodrome pairs in upper half of the leaf.

Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Order EBENALES.

Family SAPOTACEÆ.

Genus BUMELIA Swartz.

Bumelia apalachicolensis Berry, n. sp.

Plate IX, figure 4.

Leaves oblong-obovate in general outline, with an evenly rounded apex and a narrowed cuneate base. Length about 4 centimeters; maximum width, above the middle of the leaf, about 1.9 centimeters. Margins entire, rather full. Texture coriaceous. Petiole short and stout, about 2.5 millimeters in length. Midrib stout, especially proximad, curved. Secondaries thin, numerous, 10 to 12 subopposite to alternate pairs, subparallel, at approximately regular intervals; they diverge from the midrib at angles of about 40° and are camptodrome in the marginal region. Tertiaries immersed in the leaf substance.

In the modern flora the genus Bumelia embraces about 20 species of shrubs and mostly small trees, confined to the Western Hemisphere, where they are distributed from the southern United States through the West Indies, Mexico, and Central America to Brazil. Some of the species range northward to Virginia and southern Illinois. They inhabit for the most part the strand, sandy soil near the coast, river bottoms, and the borders of swamps. Fossil species of Bumelia are numerous and the genus was probably cosmopolitan during the Tertiary—it was certainly common in the European area. It has been continuously represented in southeastern North America since the Upper Cretaceous. Four lower Eocene species from this area have been described, one of which, *Bumelia pseudotenax* Berry, from the Wilcox group of northern Mississippi, is not unlike the Alum Bluff species but somewhat smaller and relatively narrower. Other species are present in the deposits of the Claiborne and Vicksburg groups.

Compared with existing American species the present form is closer to the temperate than to the tropical species. It is intermediate between *Bumelia tenax* Willdenow and *B. lanuginosa* Persoon and may stand in an ancestral relationship to these modern forms. The former ranges along the coast from Cape Canaveral to North Carolina and the latter from northern Florida along the Gulf coast and up the Mississippi Valley to southern Illinois and is abundant and of its largest size in the river bottoms of eastern Texas.

Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Genus SAPOTACITES Ettingshausen.

Sapotacites spatulatus Berry, n. sp.

Plate X, figure 2.

Leaves of medium size, obovate or spatulate in general outline, with a broadly rounded apex, from which it narrows gradually with nearly straight lateral margins to the sharply cuneate base. Length about 7 centimeters; maximum width in the upper part of the leaf, about 2.75 centimeters. Margins entire. Texture coriaceous. Petiolar portion missing. Midrib stout but more or less immersed. Secondaries obsolete by immersion. Tertiaries shown in microscopic preparations to form a very close meshed areolation.

Sapotacites is a form genus for generically undifferentiated or undeterminable members of the family Sapotaceæ, and numerous species that range from the Upper Cretaceous through the Tertiary have been described. It is possible to refer many of these ancient species, such as the numerous forms in the flora of the Wilcox group, to Bumelia, Mimusops, Sideroxylon, Chrysophyllum, and other allied genera. The present form is much like a number of existing species of Mimusops as well as some forms of Bumelia. The family is chiefly tropical and subtropical.

No fossil species are especially close to the present one, although it shows considerable resemblance to *Chrysophyllum sagorianum* Ettingshausen,[1] from the Aquitanian of Sagor, in Carniola.

Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

Family EBENACEÆ.

Genus DIOSPYROS Linné.

Diospyros brachysepala Alex. Braun.

Plate X, figure 3.

Diospyros brachysepala. Alex. Braun, Die Tertiär-Flora von Öningen: Neues Jahrb., 1845, p. 170.

Diospyros brachysepala. Heer, Flora tertiaria Helvetiæ, vol. 3, p. 11, pl. 102, figs. 1–14; pl. 153, fig. 39b, 1859.

Diospyros brachysepala. Friedrich, Beiträge zur Kenntniss der Tertiärflora der Sachsen, pp. 63, 119, 126, 253, 255, pl. 6, fig. 1, 1883.

Diospyros brachysepala. Ward, Types of the Laramie flora: U. S. Geol. Survey Bull. 37, p. 104, pl. 49, figs. 1, 2, 1887.

This early described species has been recorded from a large number of American and Eurasian localities ranging in age from basal Eocene to Pliocene. It is improbable that a single species existed for so long a period, and I have therefore reduced the synonymy of

[1] Ettingshausen, Constantin, Die fossile Flora von Sagor in Krain, pt. 2, p. 14, pl. 12, figs. 19–21, 1877.

this species to a few representative citations.[1] The species has been recorded by Lesquereux, Ward, and others from the lower Eocene of the Rocky Mountain area, as well as by Heer from West Greenland. I am not certain that all these records are correct, for *Diospyros brachysepala* is typically an Oligocene-Miocene form. It is found in the type area in both the Aquitanian and Burdigalian.

The Alum Bluff leaves, like most of the material referred to this species, are relatively small, about 5.5 centimeters in length and 2.8 centimeters in maximum width, midway between the apex and the base, which are about equally pointed, the general outline being almost elliptical. The midrib is stout and the secondaries thin, numbering six or seven subopposite to alternate camptodrome pairs. The leaves here described are close to a number of examples figured by Heer from the type locality, but are relatively slightly broader than some of the forms referred to this species by different authors. In some respects they are very similar to *Diospyros lamarensis* Knowlton,[2] from Lamar (probably upper Miocene), in Yellowstone Park.

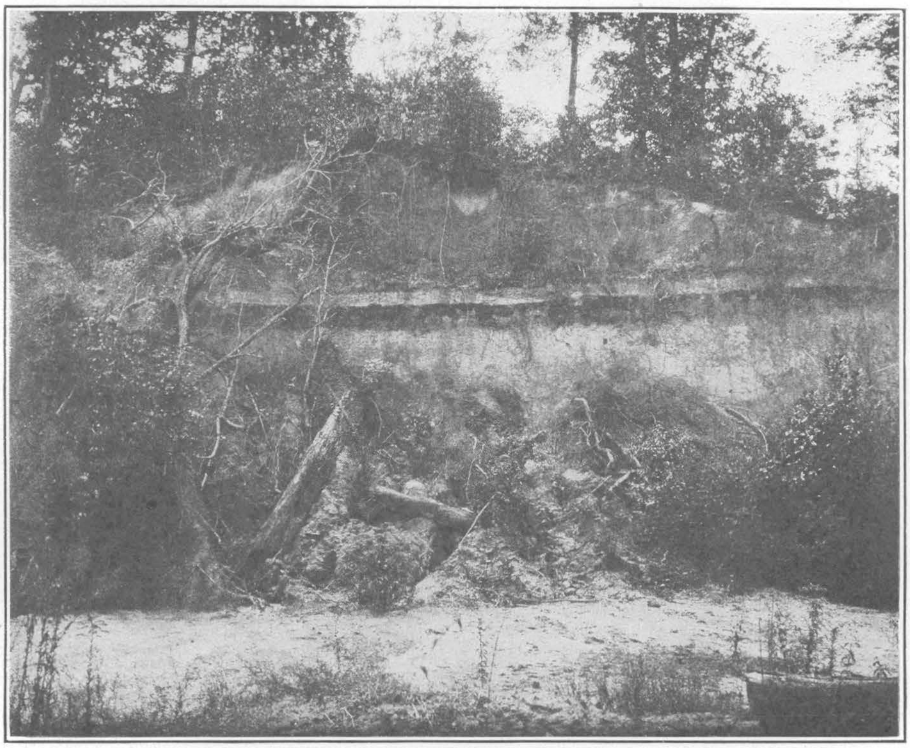
Occurrence: Alum Bluff formation, Alum Bluff, Liberty County, Fla. (collected by E. W. Berry).

Collection: United States National Museum.

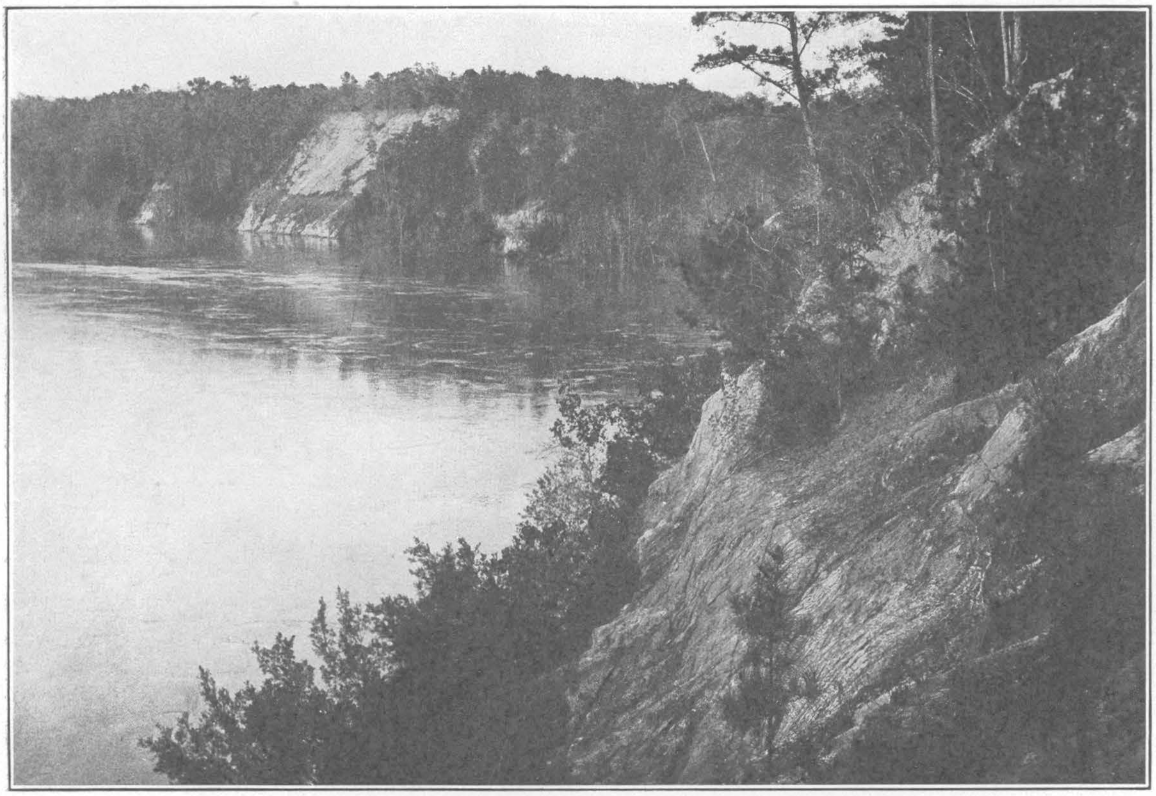
[1] A much more complete synonymy is given in my paper The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91 (in press).

[2] Knowlton, F. H., U. S. Geol. Survey Mon. 32, pt. 2, p. 751, pl. 95, figs. 5, 6; pl. 96, fig. 4, 1899.

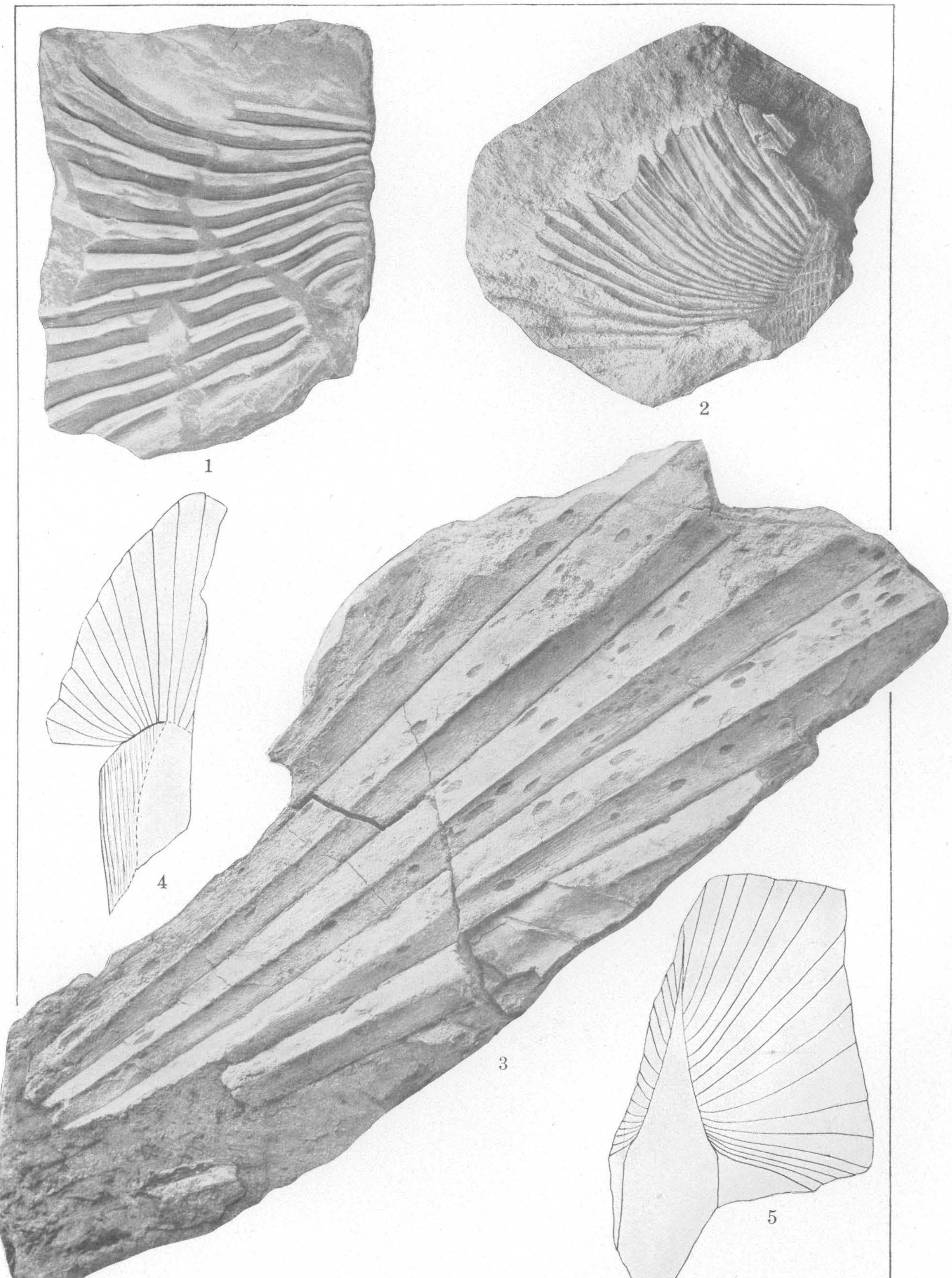
PLATES VII-X.



A. PLANT-BEARING BEDS IN THE HATTIESBURG CLAY NEAR RAGLAN, FORREST COUNTY, MISS.



B. PLANT-BEARING BEDS AT THE TYPE LOCALITY OF THE ALUM BLUFF FORMATION, ALUM BLUFF, APALACHICOLA RIVER, LIBERTY COUNTY, FLA.



FOSSIL PLANTS FROM THE ALUM BLUFF FORMATION AT ALUM BLUFF, FLA.

PLATE VIII.

FIGURES 1–5. *Sabalites apalachicolensis* Berry, n. sp., from the Alum Bluff formation, Alum Bluff, Liberty County, Fla.

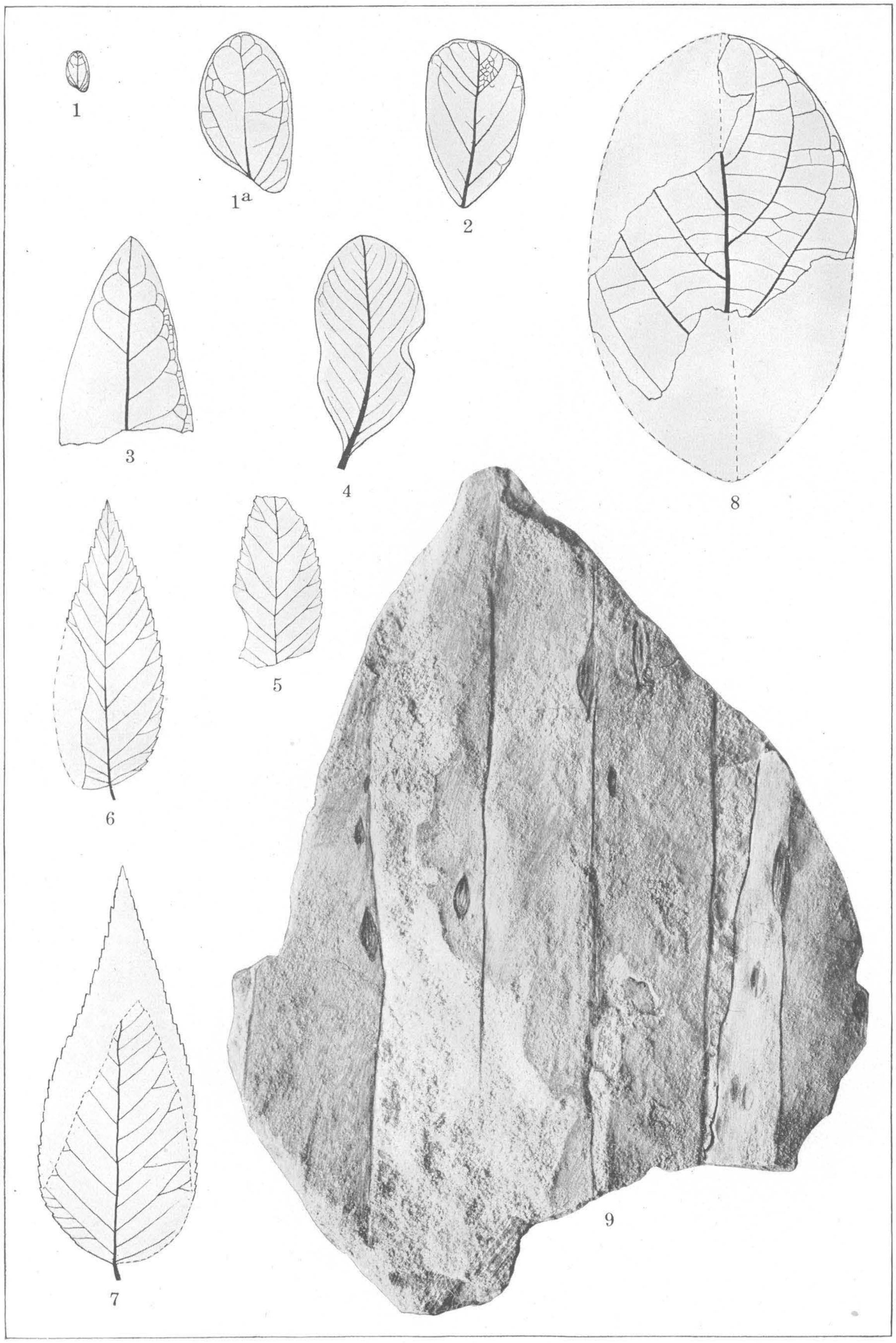
Figures 2 and 5 show prolongation of the rachis as a midrib on the under side of the leaf.

Figure 3 shows fragment of a leaf infested with *Pestalozzites sabalana* Berry, n. sp.

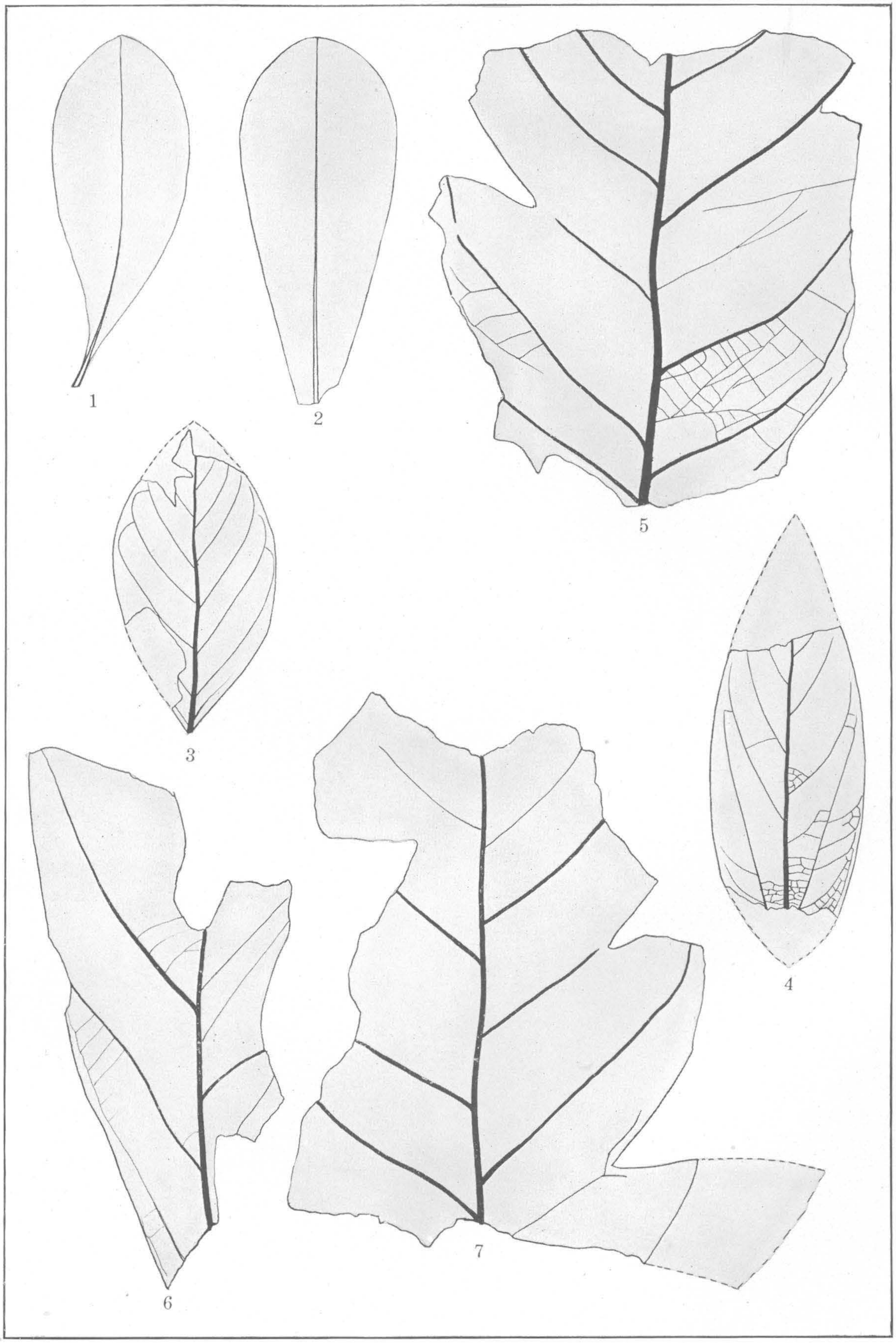
Figure 4 shows the upper side of a leaf base and the termination of the rachis as a truncate ligule.

PLATE IX

FIGURE 1. *Cæsalpinia sellardsi* Berry, n. sp.
FIGURE 1a. The same, × 5.
FIGURE 2. *Fagara apalachicolensis* Berry, n. sp.
FIGURE 3. *Nectandra apalachicolensis* Berry, n. sp.
FIGURE 4. *Bumelia apalachicolensis* Berry, n. sp.
FIGURES 5–7. *Ulmus floridana* Berry, n. sp.
FIGURE 8. *Rhamnus apalachicolensis* Berry, n. sp.
FIGURE 9. *Sabalites apalachicolensis* Berry, n. sp. Portion of a very large leaf infested with *Pestalozzites sabalana* Berry, n. sp.



FOSSIL PLANTS FROM THE ALUM BLUFF FORMATION AT ALUM BLUFF, FLA.



FOSSIL PLANTS FROM THE ALUM BLUFF FORMATION AT ALUM BLUFF, FLA.

PLATE X.

FIGURE 1. *Pisonia apalachicolensis* Berry, n. sp.
FIGURE 2. *Sapotacites spatulatus* Berry, n. sp.
FIGURE 3. *Diospyros brachysepala* Alexander Braun.
FIGURE 4. *Cinnamomum scheuchzeri* Heer.
FIGURES 5–7. *Artocarpus lessigiana floridana* Berry, n. var.

30830°—17——5

THE PHYSICAL CONDITIONS INDICATED BY THE FLORA OF THE CALVERT FORMATION.

By Edward Wilber Berry.

INTRODUCTION.

The object of the present paper is to give a summary of the small flora preserved in the Miocene diatomaceous beds of the Calvert formation in the District of Columbia and Virginia, and more especially to discuss its bearing on the physical conditions of the Calvert epoch. Subsequent to the middle Eocene the next abundant marine fauna preserved along the middle Atlantic coast is that of the Calvert formation of the Chesapeake group. Although Miocene faunas so low in the stratigraphic column are known south of Virginia only in the vicinity of Porters Landing, Savannah River, Ga., closely related but younger Miocene faunas extend southward at least as far as Florida, where the containing formation rests unconformably on beds in which occur the warmer-water faunas of the Apalachicola group.

The change from the Apalachicola faunas to those of the Miocene constitutes one of the most striking faunal changes of the later Tertiary in southeastern North America, and its emphasis by Dall and others has led to what I believe to be a misconception of the real climatic conditions of Calvert time. Likewise from the fact that the conspicuous deposits of diatomaceous ooze in existing marine waters are in the polar oceans it has been unscientifically assumed that the diatomaceous beds so characteristic of the Calvert formation must have been formed by species which had a more or less comparable environment.

CHARACTER AND EXTENT OF THE CALVERT FORMATION.

The Calvert formation, named by Shattuck [1] in 1902 from the Calvert Cliffs, in Calvert County, Md., consists of 200 to 400 feet of diatomaceous earth, sandy clays, and marls. It is typically developed in Maryland, where the basal member (Fairhaven) comprises about 65 feet of diatomaceous earth, locally argillaceous and showing occasional influxes of sands. The Calvert has been recognized in southern New Jersey and Delaware. It is also well represented in Virginia but disappears in the southern part of that State by the transgression of the St. Marys formation, which completely buries it in North Carolina, overlapping on the crystalline rocks of the Piedmont Plateau in some areas.

Fossil land plants have been found in the Calvert at Richmond, Va., in the District of Columbia along the Benning road near the District line, and at Good Hope Hill. The formation crops out on the Good Hope road at a point near the top of the hill, where a few feet of light-colored clay (Calvert) rests unconformably on the fossiliferous beds of the Magothy formation (Upper Cretaceous). The Calvert is overlain by gravels of late Tertiary or early Pleistocene age. This locality is one of the most northwesterly points at which the Calvert can be recognized with certainty, and it must also have been near the landward margin of the Calvert sea. No invertebrates are associated with the plants at this outcrop.

At the Richmond locality the Calvert consists of very clayey diatomaceous earth 40 to 50 feet in thickness, which rests unconformably upon remnants of the Eocene or upon the underlying Lower Cretaceous or crystalline rocks and is overlain by Pleistocene deposits. That this locality also was near the shore line of the Calvert sea, as it is near the landward limit of the existing Calvert deposits, is indicated not only by the more clayey nature of the materials compared with similar diatomaceous deposits elsewhere in the Calvert formation but

[1] Shattuck, G. B., The Miocene formation of Maryland: Science, new ser., vol. 15, p. 906, 1902.

by the contained plant fossils, as well as by considerable comminuted lignite, that in places forms layers 5 to 12 millimeters thick. The Calvert contains marine invertebrates in the immediate vicinity of this outcrop, and associated with the plants are *Nassa peraltoides* Martin and *Disciniscа lugubris* (Conrad), the latter a species which occurs in shallow water free from sand.

FAUNA OF THE CALVERT FORMATION.

The fauna of the Calvert formation is extensive, particularly in the marls that overlie the diatomaceous beds. In addition to the remains of marine vertebrates, which are in general wide-ranging and of little significance in ecology, there is a considerable molluscan fauna. From the Calvert of Maryland 235 species of Mollusca have been described. About 100 species have been recorded from the Virginia extension of these beds, but this number will be considerably increased when the studies of Dr. J. A. Gardner are published. Twenty-three of the Calvert species have been identified in the Florida Miocene (Jacksonville and Choctawhatchee formations), where 40 per cent of the fauna is common to the Chesapeake group, resembling more specifically the faunas of the Miocene formations younger than the Calvert. From an analyses of these Maryland faunas Dall,[1] a few years ago, concluded that they indicated shallow marine waters and temperatures somewhat warmer than those of the present time in the latitude of Maryland. Of the species that persist in the existing fauna, the bulk are found south of Cape Hatteras. I see no reason for doubting Dall's conclusions, which obviously preclude the "cold" or even the "cool temperate" conditions that have commonly been considered as characteristic of the Chesapeake group.

The United States hydrographic charts give the mean temperature of the surface water of the Atlantic in the latitude of Maryland from December to May as 55°, and from June to November as 71.5°. The figures for Massachusetts Bay are 45° and 63.5°, respectively. The figures for the vicinity of Beaufort, N. C., which is immediately south of Cape Hatteras and which would appear to afford conditions corresponding to Dall's qualitative estimate, are 65+° for December to May and 76° for June to November. If Dall's estimate is reasonably correct it would indicate that the mean annual temperature of the water in which the Calvert molluscan fauna lived was close to 70°. The mean for the year at the surface off the Maryland coast is 63°, and at Beaufort it is 70°, and although the bottom temperatures are slightly less than the surface temperatures they are more uniform and for shallow seas like the Calvert would not be appreciably lower.

[1] Dall, W. H., Maryland Geol. Survey, Miocene, pp. cxxix–clv, 1904.

FLORA OF THE CALVERT FORMATION.

COMPOSITION AND ENVIRONMENT.

The most abundant plant remains in the Calvert are the siliceous tests of diatoms. These have been much studied by diatomists, who have identified a very large number of species. I am indebted to Dr. Albert Mann for the statement that the Calvert diatom flora indicates a comparatively shallow, strictly marine habitat with relatively warm or subtropical temperature.

The remains of land plants preserved in the strictly marine beds of the Calvert are few both in number of species and in number of individuals. As a result of the present study I am able to enumerate 26 species—16 from Virginia and 17 from the District of Columbia, with 7 forms common to the two areas. The flora includes 1 pteridophyte (Salvinia), 2 conifers (Taxodium and Pinus), and 23 dicotyledons. Leguminous forms and oaks predominate, although the cypress (Taxodium) is by far the most common form at Richmond, where cone scales and seeds as well as an abundance of the deciduous twigs are preserved.

Although this flora is so small it fortunately comprises forms whose characters indicate very clearly the physical conditions along the shore of the Calvert sea. The accompanying table indicates the most similar fossil and existing species:

Comparison of Calvert flora with most similar fossil and existing forms.

Calvert flora.	District of Columbia.	Richmond.	Most similar fossil form.		Most similar existing form.	
			Name.	Horizon.[a]	Name.	Habitat and range.
Salvinia formosa Heer?	....	×	Salvinia formosa Heer	Tortonian of Baden	Salvinia natans (Linné) Hoffmann.	Aquatic; widely distributed in Eurasia.
Pinus sp	×	....			Pinus tæda Linné	Wet, coastal; Delaware to Texas.
Taxodium dubium (Sternberg) Heer.	×	×	Taxodium dubium (Sternberg) Heer.	Eocene to Pliocene	Taxodium distichum (Linné) L. C. Richard.	River swamps; Delaware to east Texas.
Salix ræana Heer	....	×	Salix ræana Heer	Tertiary of Greenland. Mascall formation of Oregon.	....	
Quercus calvertonensis Berry	×	×	....	....	Quercus alba Linné	Canada to Florida and Texas.
Quercus lehmanni Hollick	×	....	....	....	Quercus emoryi Torrey	Arid uplands; western Texas, southern Arizona, and New Mexico.
Quercus chapmanifolia Berry	×	....	Some of forms referred by Heer to Quercus myrtilloides Unger.	Miocene of Switzerland.	Quercus chapmani Sargent	Sandy, coastal· Georgia and Florida.
Carpinus grandis Unger	....	×	Carpinus grandis Unger	Tortonian of Europe. Mascall formation of Oregon. Tertiary of Greenland.	Carpinus caroliniana Walter	Bottoms and swamps; southern Canada to Florida.
Ulmus basicordata Hollick	×	×	Ulmus minuta Goeppert	Tortonian of Europe	Ulmus alata Michaux	Uplands and swamps; Virginia to Texas.
Planera ungeri Ettingshausen	....	×	Planera ungeri Ettingshausen.	Tortonian of Europe. Tertiary of Greenland.	Planera aquatica Gmelin	Swamps; North Carolina to Florida and Texas.
Ficus richmondensis Berry	....	×	Ficus tiliæfolia (Alex. Braun) Heer.	Tortonian of Europe	....	
Platanus aceroides Goeppert	....	×	Platanus aceroides Goeppert.	Tortonian of Baden. Tertiary of Greenland.	Platanus occidentalis Linné	Bottom lands; New England to Florida and Texas.
Phyllites cercocarpifolia Berry	×	....	....	....	Cercocarpus breviflorus Gray	Dry ridges; western Texas, southern Arizona, New Mexico, and Mexico.
Cæsalpinia ovalifolia Hollick	×	....	Cæsalpinia townshendi Heer.	Tortonian of Baden	Cæsalpinia species	American Tropics and subtropics.
Cassia toraformis Berry	×	....	Cassia lignitum Unger	Tortonian of Europe	Cassia tora Linné	Sandy; Virginia to Florida and tropical America.
Podogonium virginianum Berry	×	×	Podogonium obtusifolium Heer. Leguminosites deperditus Heer.	Tortonian of Baden	....	
Dalbergia calvertensis Berry	×	×	Cæsalpinia micromera Heer	do	....	
Leguminosites calvertensis Berry	....	×	Pods referred by Heer to Acacia.	do	Leucæna greggi Watson	Ravines and banks; western Texas and Mexico.

[a] Many of these forms are wide-ranging and have been identified from various horizons. Only the most similar materials are cited.

Comparison of Calvert flora with most similar fossil and existing forms—Continued.

Calvert flora.	District of Columbia.	Richmond.	Most similar fossil form.		Most similar existing form.	
			Name.	Horizon.[a]	Name.	Habitat and range.
Rhus milleri Hollick	×	×	Rhus pyrrhæ Unger	Tortonian of Baden		
Celastrus bruckmanni Alex. Braun.		×	Celastrus bruckmanni Alex. Braun.	Tortonian of Europe Tertiary of Greenland		
Ilex calvertensis Berry	×				Ilex vomitoria Aiton	Coastal; south Atlantic and Gulf States.
Berchemia priscaformis Berry	×		Berchemia prisca Saporta Berchemia multinervis (Alex. Braun) Heer.	Aquitanian of France Tortonian of Baden	Berchemia scandens (Hill) Trelease.	Low woods; Virginia to Texas.
Nyssa gracilis Berry		×	Nyssa arctica Heer	Tertiary of Greenland	Nyssa biflora Walter	Swamps and pond borders; Maryland to Louisiana near coast.
Vaccinium cf. V. textum Heer	×		Vaccinium textum Heer	Tortonian of Baden		
Pieris scrobiculata Hollick	×				Pieris nitida (Bartram) Bentham.	Wet woods; Virginia to Cuba.
Fraxinus richmondensis Berry		×			Fraxinus americana Linné Fraxinus pennsylvanica Marshall.	Canada to Texas.
Phyllites sp. Hollick	×					

[a] Many of these forms are wide-ranging and have been identified from various horizons. Only the most similar materials are cited.

Among the recent species with which the Calvert forms are compared three range as far north as southern Canada and one other ranges into New England. On the other hand, all the forms, including the four just mentioned, range southward to Florida or Texas and five of these extend into the American Tropics. It is obvious that these wide-ranging forms are of slight value in an endeavor to estimate the climatic conditions along the coast in Calvert time. More significance attaches to the northern limits of the other existing forms with which those of the Calvert are compared. Three of these have their northern limits in southern Arizona and New Mexico, two in Georgia, two in North Carolina, four in Virginia, one in Maryland, and two in Delaware. Some of the comparisons with recent forms are closer or more significant than others. Among these may be cited those with *Taxodium distichum*, *Quercus chapmani*, *Planera aquatica*, *Berchemia scandens*, and *Pieris nitida*. Of these, the bald cypress (*Taxodium distichum*) reaches its northern limit in southern Delaware; *Quercus chapmani* is confined to the coast of Georgia and the Gulf of Mexico; Planera reaches northward to the Coastal Plain of North Carolina; and Berchemia and Pieris extend to the Coastal Plain of Virginia. It is obvious that if these comparisons are legitimate the Calvert flora would find its most favorable conditions for existence along the present south Atlantic and Gulf coasts.

Another method of approach is furnished by comparing the Calvert flora with the contemporaneous floras of Europe. Of the 26 Calvert species, 7 are identical with and 10 are extremely close to forms of the Tortonian of Europe. The Tortonian has a very extensive flora, and as a result of the elaborate analysis by Heer it was considered to indicate a mean annual temperature of 65°.

Regarding the specific environment of the different Calvert species, I consider the following as denizens of river or estuary swamps:

Salvinia formosa.	Fraxinus richmondensis.
Taxodium dubium.	Pinus sp.
Nyssa gracilis.	

The following may be considered as dwellers on river bars or behind coastal sand dunes:

Salix ræana.	Platanus aceroides.
Ulmus basicordata.	Berchemia priscaformis.
Cassia toraformis.	Carpinus grandis.
Pieris scrobiculata.	

Those which probably flourished in low bottoms, on the lower flood plains of streams, are

Carpinus grandis.	Podogonium virginianum.
Planera ungeri.	Leguminosites calvertensis.
Platanus aceroides.	Ficus richmondensis.
Berchemia priscaformis.	Pieris scrobiculata.

Most of these could readily live also in river or estuary swamps.

The species which may legitimately be considered to have been inhabitants of the strand or of coastal dunes are

Quercus calvertonensis.	Dalbergia calvertensis.
Quercus lehmanni.	Rhus milleri.
Quercus chapmanifolia.	Ilex calvertensis.
Phyllites cercocarpifolia.	Vaccinium cf. V. textum.
Cæsalpinia ovalifolia.	Celastrus bruckmanni.
Cassia toraformis.	Pinus sp.

All but Salvinia and Cassia were probably arborescent, and Cassia may have been. All the dicotyledons except Fraxinus, Carpinus, Platanus, Ficus, and *Quercus calvertonensis* show marked reduction of the leaf laminæ, clearly indicating a sandy habitat or a swamp habitat, the latter being physiologically dry and in its effects much like the former.

The leaves of the oaks, Berchemia, Podogonium, *Phyllites cercocarpifolia*, Dalbergia, Rhus, Ilex, Vaccinium, and Celastrus are coriaceous or subcoriaceous, and those of the Pieris are tomentose, both features tending to prevent transpiration and indicating a physiologically dry habitat as well as exposure to abundant sunshine.

In comparing the two localities, that at Richmond clearly indicates a low coast which was lined with cypress swamps and in which the very inconsiderable run-off carried only the finest muds. That in the District of Columbia, in its small-leafed oaks, Ilex, Vaccinium, Pieris, and abundance of Leguminosæ, as clearly indicates a region of dunes comparable with the present Santa Rosa Peninsula, between Pensacola Bay and the Gulf of Mexico.

Physical conditions may produce decided differences in the flora of the continental margin and the marine life of the sea which washes it, as for example in the English Pliocene, where the only avenue of immigration for terrestrial plants and fresh-water mullusks was from the south, while the only avenue of immigration for the marine fauna lay in the cool currents that entered the North Sea from the north. However, the Calvert fossils do not represent a northward extension of the south Atlantic and

Gulf flora along the Coastal Plain and a southward migration of a marine shallow-water fauna in the opposite direction along the coast, but both floral and faunal evidence are in accord.

In this connection it is of interest to call attention to the fact that five of the Calvert plants occur in the late Eocene or Oligocene of western Greenland, in latitude 70° N. This Arctic flora I believe to be contemporaneous with those more southern floras of the late Eocene (Jackson) or early Oligocene (Catahoula and Vicksburg) which are most tropical in their facies. It seems also to be established that with the gradual lowering of temperatures during later Tertiary time this circumpolar flora spread southward over North America and Eurasia.

PROBABLE AGE.

Seven of the Calvert plants, or 26.9 per cent, are common to the Tortonian of Europe, and ten others, or 38 per cent, are represented in the Tortonian by very similar forms. In view of the fact that these floras spread into both regions from a common and equally accessible source, as I have just stated, the evidence that the Calvert flora indicates a Tortonian age is as conclusive as intercontinental correlations can ever be. Compared with other American floras of Miocene age, that of the Calvert has little in common with the described Miocene floras from Colorado, Idaho, Oregon, or California, which are all lake or river valley floras of moist upland forest types.

CONCLUSIONS.

The Calvert flora was a coastal flora of strikingly warm-temperate affinities, comparable with the existing coastal floras of South Carolina and Georgia along the south Atlantic coast or with those along the coast of the Gulf of Mexico from western Florida to eastern Texas. The general climatic features it indicates are in accord with those which may be legitimately deduced from the evidence of the marine faunas. The climate of the Chesapeake Miocene epoch, cooler undoubtedly than that of the Apalachicola or preceding epochs, was neither cold nor cool temperate.

The age indicated by the Calvert flora is middle Miocene, or in terms of European geology Tortonian.

NEW SPECIES OF PLANTS.

Class GYMNOSPERMÆ.

Order CONIFERALES.

Family PINACEÆ.

Genus PINUS Linné.

Pinus sp.

Plate XII, figure 1.

A somewhat macerated seed of Pinus of the *Pinus tæda* type occurs at Good Hope Hill. The material is insufficient for characterization.

Pinus tæda Linné ranges from Delaware southward along the coast to Texas and extends up the Mississippi Valley to Tennessee and Arkansas.

Class ANGIOSPERMÆ.

Order FAGALES.

Family FAGACEÆ.

Genus QUERCUS Linné.

Quercus chapmanifolia Berry, n. sp.

Plate XI, figures 1, 2.

Leaves small, oblong-obovate in general outline, with a rounded apex and a wide or narrowly cuneate, ultimately slightly rounded base. Length from 27 to 45 millimeters; maximum width, at or above the middle, from 14 to 30 millimeters. Margins entire, slightly undulate. The lateral margins ascend to or above the middle, where they curve to form irregular and unequally developed rounded lobes subtending usually shallow and open rounded sinuses. A second short and broadly rounded lobe may be developed, usually on only one side, in the apical region. Petiole short and stout enlarged proximad, 2 to 3 millimeters in length. Midrib stout, usually curved or flexuous, prominent on the lower surface of the leaf. Secondaries of varying caliber dependent on the extent to which lobes are developed; in the prominently lobed specimen shown in figure 2 a subopposite pair are stout and prominent on the lower surface of the leaf, where the lobation is feeble, as in figure 4. The secondaries are thin. There are as many craspedodrome secondaries as there are lobes—two or three to a leaf; the rest of the secondaries are camptodrome; all are somewhat irregularly spaced and rather straight in their courses, their angles of divergence depending on the relative width of the leaves. Texture coriaceous.

This significant new species is rather clearly marked off among previously described fossil forms. Among existing forms its size and general outline as well as its limits of variation are almost exactly those of *Quercus chapmani* Sargent. This may be readily seen without extended discussion by the ink prints of the leaves of the latter species introduced for comparison and shown in figures 3 to 8 of Plate XI.

This similarity is, I believe, an indication of relationship, and in its light the habitat of the existing species becomes of special interest. *Quercus chapmani* is a small tree, or more commonly a shrub, inhabiting sandy barrens near the coast, of rare occurrence from South Carolina to Florida along the Atlantic coast, reaching its maximum of abundance and development along the Gulf coast of western Florida from the shores of Tampa Bay to Pensacola. The leaves figured come from the Santa Rosa Peninsula, where it is typically developed and where the environment is comparable with that of Miocene time along the shores of the shallow Calvert sea.

Occurrence: Good Hope road, Anacostia Heights, D. C.

Quercus lehmanni Hollick.

Plate XI, figures 9–11.

Quercus lehmanni. Hollick, Miocene, p. 483, figs. 1a, 1b, Maryland Geol. Survey, 1904.

This species was briefly described by Hollick in 1904. Recent material collected from the type locality enables me to give the following somewhat fuller characterization:

Leaves small and narrow, oblong in general outline. Length from 21 to 38 millimeters; maximum width, across the median marginal lobes, from 14 to 17 millimeters. Apex conically pointed. Base broadly rounded, generally somewhat inequilateral. Margins with one to three irregularly spaced reduced lobes on each side; these lobes are more or less developed, short, and conical and are little more than coarse teeth; they subtend usually open sinuses, although in some specimens the lobes are directed upward instead of outward and the sinuses are correspondingly narrow. Petiole short and stout. Midrib stout, straight, or curved, prominent on the lower surface of the leaf. Secondaries thin, two to four pairs; they diverge from the midrib at angles of about 45° and ascend in straight or somewhat flexuous courses; a craspedodrome secondary runs to the tip of each lobe, and a basal one on each side arches along the lower lateral margin. Tertiaries obsolete. Texture coriaceous. The lobes are irregularly spaced; if there is but one on one side there are usually two on the other, and if there are two on one side there are usually three on the other; they may all be above the middle of the leaf, as in figure 9, but often there is a small oblique one lower down, as in figures 10 and 11. Midway between the apex and the base, where the leaf is consequently widest, they are subopposite, as are the corresponding secondaries.

These characteristic leaves are not uncommon, but like most of the plant material in the Calvert formation they are usually much broken. Their size, form, and texture are indicative of barren soil, bright sunshine, and sparse rainfall. Compared with existing species they are found to resemble the toothed leaves sometimes developed on *Quercus virginiana* Miller, a coastal species of southeastern North America, which is also abundant in the Pleistocene and which in the form of *Quercus previrginiana* Berry is exceedingly abundant in the Pliocene of the Gulf coast. Most of the leaves of *Quercus virginiana* are oblong, elliptical, or obovate with merely undulate margins, and the significance of the occasional toothed leaves is unknown. A modern species with which *Quercus lehmanni* may be more legitimately compared is *Quercus emoryi* Torrey. The latter has the small narrow leaves with rounded bases and irregular teeth. They differ somewhat from the fossil leaves in their proportions, having generally a broader base, but many leaves can be selected that exactly match the fossil. *Quercus emoryi* is a stout tree of the uplands of western Texas and southern New Mexico and Arizona, and although it is not necessarily directly affiliated with this Miocene form of the Atlantic coast, it is not improbable that the two forms have a common ancestor which once flourished in an intermediate area.

Occurrence: Good Hope road, Anacostia Heights, D. C.

Order **URTICALES.**

Family **ULMACEÆ.**

Genus **ULMUS** Linné.

Ulmus basicordata Hollick.

Plate XII, figure 2.

Ulmus basicordata. Hollick, Miocene, p. 484, fig. 1f, Maryland Geol. Survey, 1904.

This characteristically small Ulmus was compared by Hollick with the cosmopolitan *Planera ungeri* Ettingshausen, especially with the type material[1] from the late Miocene of Austria. This protean and probably composite species has a recorded range from the Eocene to the Pleistocene and a geographic distribution from Japan and Manchuria throughout Europe to North America, Iceland, and Greenland. It has been recorded by me from the Calvert formation at Richmond, Va., and that material is certainly quite distinct from *Ulmus basicordata,* whatever may be thought of some of the European records of *Planera ungeri.*

In my judgment *Ulmus basicordata* finds its closest European relative in *Ulmus minuta* Goeppert.[2] This little species has been recorded from a large number of European localities, ranging in age from the middle Miocene to the Pliocene. The American *Ulmus basicordata* may be compared more particularly with the material of *Ulmus minuta,* from the Tortonian of Baden, on the Swiss border, described by Heer.[3]

Occurrence: Richmond, Va., and Good Hope Hill, D. C.

Order **ROSALES.**

Family **ROSACEÆ.**

Genus **PHYLLITES** of authors.

Phyllites cercocarpifolia Berry, n. sp.

Plate XII, figures 3, 4.

Leaves small, obovate, with a broadly rounded tip and a cuneate base. Length about 6 millimeters; maximum width, slightly above the middle, about 3.5 millimeters. Margins entire, possibly slightly revolute. Texture distinctly coriaceous. Petiole short and stout, less than 1 millimeter in length. Midrib relatively stout and prominent. Secondaries thin but prominent, numerous, equally spaced and subparallel; about seven or eight subopposite pairs diverge from the midrib at acute angles and pursue a nearly straight ascending course to the margins, where they are abruptly camptodrome. Tertiaries obsolete.

This tiny leaf suggests a relationship with the genus Cercocarpus, of the Rosaceæ, and the resemblance is so great that I feel justified in referring the fossil to that family. Cercocarpus is a small genus of about five species of trees and shrubs confined to the dry interior and mountainous regions of the United States and Mexico. The fossil greatly resembles the entire leaves of *Cercocarpus breviflorus* Gray, a small tree of the pine and oak forests of the dry elevated ridges of southern Arizona, New Mexico, western Texas, and northern Mexico. Although I do not feel justified in referring the fossil to Cercocarpus without more conclusive evidence I believe that the resemblance noted indicates such a relationship.

Occurrence: Benning road, D. C., near District line.

Family **CÆSALPINIACEÆ.**

Genus **CASSIA** Linné.

Cassia toraformis Berry, n. sp.

Plate XII, figures 6, 7.

Leaflets small, sessile, inequilateral. Apex broad, inequilateral, slightly emarginate. Base broad, slightly pointed, inequilateral. Margins entire. Leaf substance thin. Length about 15 millimeters; maximum width, slightly below the middle, 7.5 millimeters. Midrib of medium size, nearly straight. Secondaries thin, about seven pairs, diverging from the midrib at acute angles, those in one-half of the lamina more acute, sweeping upward in ascending subparallel curves, parallel with the lower lateral margins, camptodrome. Tertiaries thin, of the Cassia type.

This species appears to be a new species of Cassia, although it may represent an allied genus of the Cæsalpiniaceæ. Among the hundreds of existing species there are a number very similar to the fossil, which I have named from its resemblance to the existing *Cassia tora* Linné, an annual of sandy soils ranging

[1] Ettingshausen, Constantin, Fossile Flora von Wien, p. 14, pl. 2, figs. 5–18, 1851.

[2] Goeppert, H. R., Tertiäre Flora von Schossnitz in Schlesien, p. 31, pl. 14, figs. 12–14, 1855.

[3] Heer, Oswald, Flora tertiaria Helvetiæ, vol 2, p. 59, pl. 79, figs. 9–13, 1856; vol. 3, p. 181, pl. 151, fig. 30, 1859.

from Virginia southward to Florida, Cuba, and tropical America.

The fossil species are numerous and range from the Upper Cretaceous to the present. Among previously described fossil forms *Cassia toraformis* is identical with some of the leaves from the Tortonian of Oeningen, Baden, which Heer [1] refers to *Cassia lignitum* Unger. It is also very similar to *Cæsalpinia escheri* Heer,[2] from Oeningen.

Occurrence: Good Hope Hill, D. C.

Order SAPINDALES.

Family ILICACEÆ.

Genus ILEX Linné.

Ilex calvertensis Berry, n. sp.

Plate XII, figure 8.

Leaves small, ovate in general outline, with a bluntly pointed apex and base, the latter slightly inequilateral. Length about 16.5 millimeters; maximum width, midway between the apex and base, about 7 millimeters. Margins entire for most of their length, apically with slight and remote denticulations. Texture subcoriaceous. Petiole short and stout, about 1.75 millimeters in length. Midrib stout and prominent proximad, attenuated distad, curved. Secondaries thin; five subopposite pairs diverge from the midrib at wide angles and are conspicuously camptodrome in the marginal region. Tertiary venation obsolete.

Ilex is a large genus with over 100 described fossil species and over 200 existing species. It ranges from the Upper Cretaceous to the present, and existing forms are found in all tropical and temperate regions except western North America, Australia, New Zealand, and New Guinea. The largest number occur in Brazil and Guiana.

Ilex calvertensis may be compared with the existing *Ilex vomitoria* Aiton, a small tree of the coastal region of the South Atlantic and Gulf States. It also resembles *Ilex vomitoriafolia* Berry, a coastal form of the lower Eocene (Wilcox group) of the Mississippi embayment, with which it may be affiliated.

Occurrence: Good Hope Hill, D. C.

[1] Heer, Oswald, Flora tertiaria Helvetiæ, vol. 3, p. 121, pl. 138, figs. 23–28, 1859.

[2] Idem, p. 111, pl. 155, fig. 21.

Order RHAMNALES.

Family RHAMNACEÆ.

Genus BERCHEMIA Necker.

Berchemia priscaformis Berry, n. sp.

Plate XII, figures 11, 12.

Leaves small, lanceolate, with equally acuminate apex and base. Length about 13 millimeters; maximum width between apex and the base, about 5.5 millimeters. Margins entire, slightly undulate corresponding with the camptodrome endings of the secondaries. Texture subcoriaceous. Petiole relatively long and slender, about 2 millimeters in length. Midrib relatively stout, somewhat curved, prominent on the lower surface of the leaf. Secondaries thin but prominent, numerous; seven or eight pairs diverge from midrib at regular intervals and acute angles, curving slightly and subparallel, camptodrome close to the margins. Tertiaries mostly obsolete, a few percurrent ones seen.

This characteristic little species is scarcely distinguishable from the smaller and more lanceolate leaves of *Berchemia scandens* (Hill) Trelease, a high-climbing shrub frequenting low woods from Virginia to Florida and from Missouri to Texas. The genus contains about 10 existing species, the others being natives of Asia and tropical Africa. About half a dozen fossil species have been described. These include a rare form in the Aquitanian of France, another in the Burdigalian of Bohemia, species in the Pliocene of France and Holland, and the widespread *Berchemia multinervis* (Alex. Braun) Heer. *B. multinervis* has a recorded range from the Tongrian to the Astian throughout central and southern Europe. It has been identified in the lower Eocene (Raton, Denver, and Fort Union formations) of the Rocky Mountain province and in the Miocene of Oregon.

The American material referred to *B. multinervis* is larger and wider than the Calvert species and has a more pronounced tertiary venation. Some of the smaller leaves of *B. multinervis* from European localities are much like *B. priscaformis*, as for example a leaf figured by Heer [3] from the Tortonian of Oeningen, Baden, which is but slightly larger or wider.

[3] Idem, pl. 123, fig. 17.

The Calvert species is named from its resemblance to *Berchemia prisca* Saporta,[1] from the Aquitanian of Peyriac, France, a very similar but slightly more oblong leaf.

Occurrence: Good Hope Hill, D. C.

Order ERICALES.

Family VACCINIACEÆ.

Genus VACCINIUM Linné.

Vaccinium cf. V. textum Heer.

Plate XII, figures 14, 15.

Several specimens of a small oval subcoriaceous leaf are indistinguishable from *Vaccinium textum* Heer,[2] from the Tortonian of Oeningen, Baden. Heer's description is as follows:

V. folius subcoriaceis, ovalibus, integerrimis, apice obtusiusculis, basi rotundatis; nervis secundariis camptodromis, areis reticulatis.

The Calvert form agrees with its European contemporary in size, general outline, and texture, as well as in secondary and tertiary venation characters. The only difference is the more acute base of the American form. The latter feature and the wide geographic separation of the two occurrences have prevented the direct reference of the American form to Heer's species.

[1] Saporta, G. de, Études sur la végétation du sudest de la France à l'époque tertiaire, vol. 2, p. 338, pl. 11, fig. 1, 1866.

[2] Heer, Oswald, op. cit., p. 190, pl. 153, figs. 40–42.

The genus contains about 125 existing species of wide geographic distribution, especially in the temperate and boreal regions of the Northern Hemisphere. It occurs, however, at high elevations in the Tropics, both north and south of the Equator, and evidently grew in intermediate areas at some past times.

The fossil species are numerous and ranged from the Eocene onward, with their maximum display during the Miocene, when they were especially abundant in southern Europe along the shores of the Mediterranean Sea of that epoch.

Occurrence: Good Hope Hill, D. C.

Family ERICACEÆ.

Genus PIERIS Don.

Pieris scrobiculata Hollick.

Plate XII, figure 13.

Pieris scrobiculata. Hollick, Miocene, p. 486, tf. 1g, Maryland Geol. Survey, 1904.

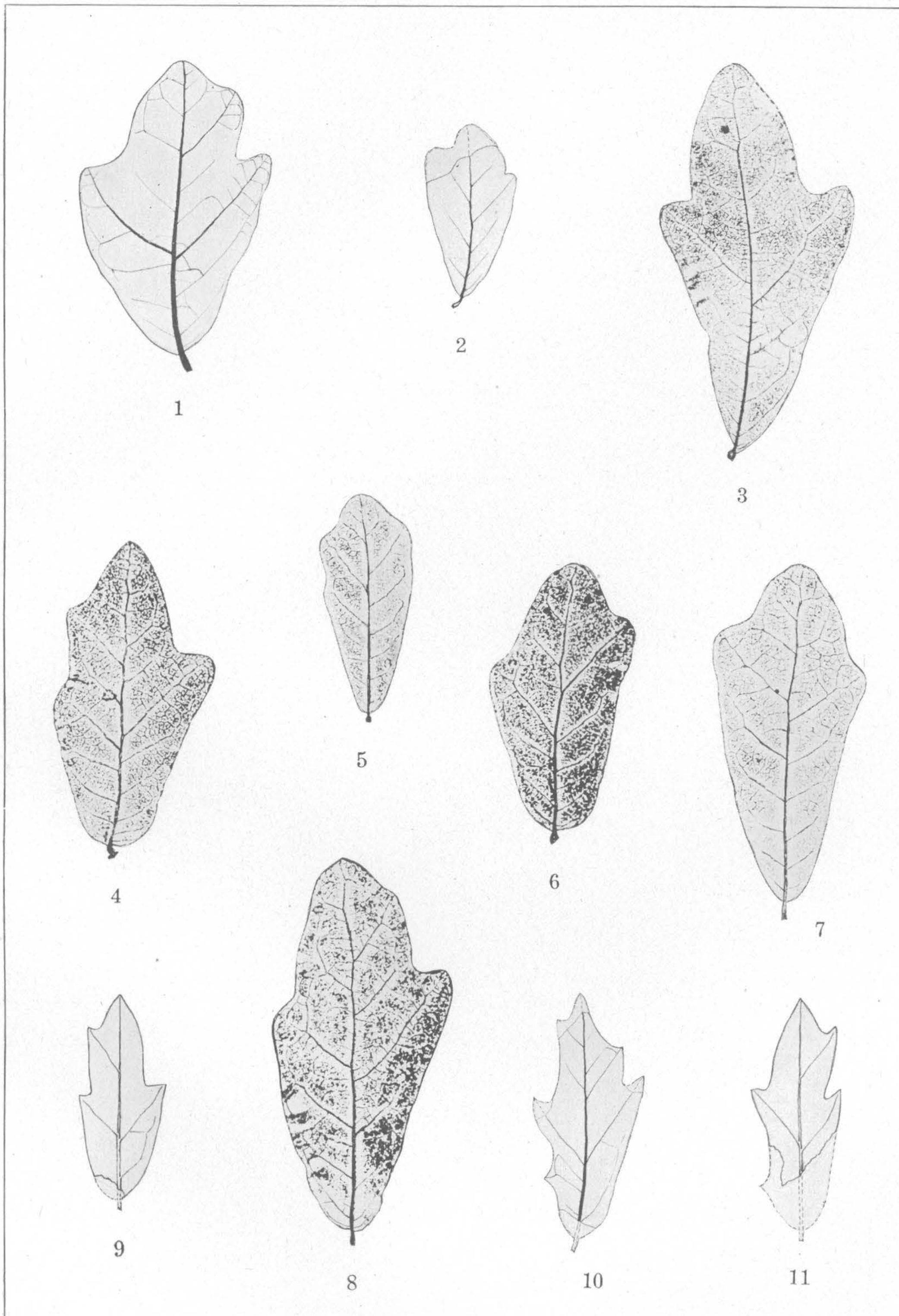
This species was described by Hollick from material obtained at the Good Hope Hill locality. He compared it with the existing *Pieris nitida* (Bartram) Bentham and Hooker, a shrub of wet woods which ranges from southeastern Virginia to Florida near the coast and is said to occur also in Cuba. Additional material from the type locality agrees with the type in outline and texture, but is only 11 millimeters in length and 5 millimeters in maximum width.

Occurrence: Good Hope Hill, D. C.

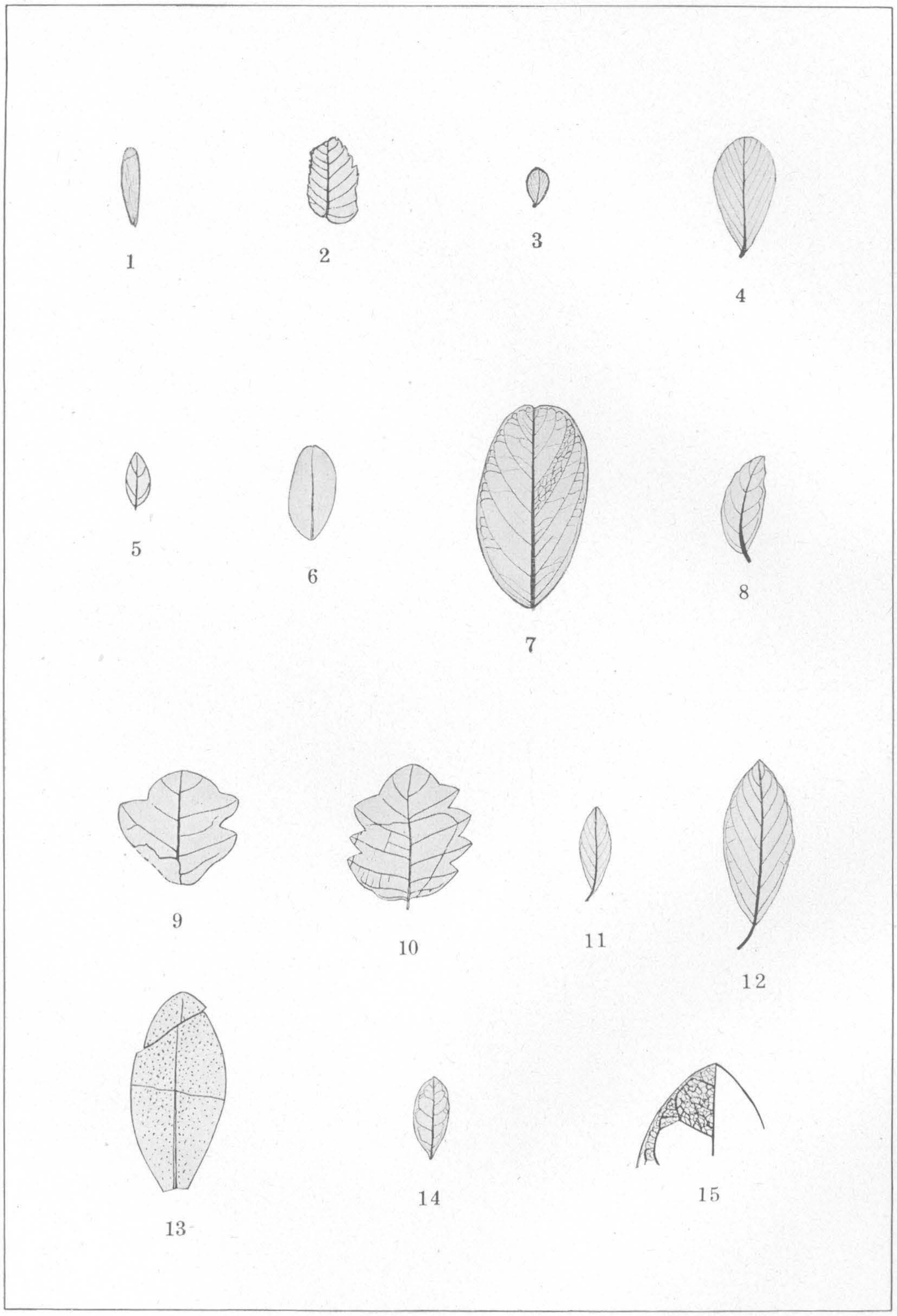
PLATES XI-XII.

PLATE XI.

FIGURES 1, 2. *Quercus chapmanifolis* Berry. Good Hope Hill, D. C.
FIGURES 3–8. *Quercus chapmani* Sargent. A modern form from Santa Rosa Peninsula, Fla.
FIGURES 9–11. *Quercus lehmanni* Hollick. Good Hope Hill, D. C. (Figs. 9 and 11 after Hollick.)



FOSSIL PLANTS FROM THE CALVERT FORMATION.



FOSSIL PLANTS FROM THE CALVERT FORMATION.

PLATE XII.

FIGURE 1. Pinus sp.
FIGURE 2. *Ulmus basicordata* Hollick. (After Hollick.)
FIGURE 3. *Phyllites cercocarpifolia* Berry.
FIGURE 4. Same, × 3.
FIGURE 5. *Cæsalpinia ovalifolia* Hollick. (After Hollick.)
FIGURE 6. *Cassia toraformis* Berry.
FIGURE 7. Same, × 3.
FIGURE 8. *Ilex calvertensis* Berry.
FIGURE 9. *Rhus milleri* Hollick.
FIGURE 10. Same, a more lobate form from Richmond, Va.
FIGURE 11. *Berchemia priscaformis* Berry.
FIGURE 12. Same, × 2.
FIGURE 13. *Pieris scrobiculata* Hollick. (After Hollick.)
FIGURE 14. Vaccinium cf. *V. textum* Heer.
FIGURE 15. Tip of same to show venation.

All but figure 10 from Good Hope Hill, D. C.

REVISION OF THE BECKWITH AND BEAR RIVER FORMATIONS OF SOUTHEASTERN IDAHO.

By G. R. MANSFIELD and P. V. ROUNDY.

INTRODUCTION AND SUMMARY.

In the detailed geologic mapping of the Wayan and Montpelier quadrangles, in southeastern Idaho and adjacent territory, it has been found necessary to apply new names to strata hitherto referred to the Beckwith and Bear River formations or to portions of the Laramie as mapped by the Hayden Survey. The two quadrangles are contiguous, and the Montpelier quadrangle lies south of the Wayan. They occupy the corner of the State and include a very narrow strip in northeastern Utah and a somewhat broader strip in western Wyoming. They lie between parallels 42° and 43° N. and meridians 111° and 111° 30′ W. The Wayan 30-minute quadrangle, the topographic map of which has not yet been published, consists of four 15-minute quadrangles, the Freedom, Lanes Creek, Crow Creek, and Slug Creek. Topographic maps of these areas are now available.

The formations to be discussed extend from the northeastern part of the Montpelier quadrangle northward through the eastern part of the Wayan quadrangle and thence northward an undetermined distance, possibly including a considerable part of the Caribou Range. They include about 17,000 feet of strata, unless there are unrecognized repetitions by folding or faulting.

Two large groups of beds are recognizable in the field. At first, in accordance with earlier interpretations, these groups were assigned respectively to the Beckwith formation, of Cretaceous and Jurassic age, and the Bear River formation, of Upper Cretaceous age. On the maps of the Hayden Survey both are included in the Laramie. There is, however, considerable lack of agreement both lithologically and faunally between these formations as exposed in the district under discussion and as exposed in the region of their type localities. Descriptions of the Beckwith formation in the areas where it has been studied show considerable variety in lithologic character. The fossil content is meager, and there is uncertainty about the upper limit of the formation.

The Bear River formation has long been known and has been studied by many geologists. It has a distinctive fauna and nearly as distinctive a lithology. The lack of agreement between the beds in the Wayan quadrangle heretofore called Bear River and the typical Bear River is so marked as to raise the question whether any of these beds can properly be assigned to that formation. The beds in the Wayan quadrangle resemble somewhat the Kootenai of Montana and Canada and may in part represent that formation. They may furnish a connecting link between the Kootenai and the Bear River.

The strata in this area that were formerly called the Bear River are here assigned to the Wayan formation, of Cretaceous, possibly Lower Cretaceous age, and the so-called Beckwith is divided into seven formations, of which the lower two are marine formations of Jurassic age, and the remaining five are nonmarine formations assigned to the Gannett group, of Cretaceous (?) age. This paper gives a statement of the stratigraphic problems involved and a description of the formations. The writers are indebted to Mr. T. W. Stanton for examination of the fossils and for helpful suggestions.

GENERAL STRATIGRAPHY OF THE AREA.

The stratigraphic sequence in southeastern Idaho is remarkably full, all the great Paleozoic and later systems being represented. The Paleozoic formations are identical in name and number with the corresponding formations of northern Utah described by Richardson,[1] except that the Threeforks limestone has not been recognized. The Idaho formations differ somewhat in thickness and character from those of the Utah section. The subjoined table shows the general character of the Mesozoic formations of the region and the relations of the formations here discussed to the others.

Mesozoic formations in southeastern Idaho.

System and series.	Formation.	Character.	Thickness (feet).
Cretaceous (Lower Cretaceous?).	Wayan formation.	Sandstones, shales, carbonaceous shales, limestones, some conglomerate	11, 800
Unconformity			
Cretaceous (?).	Gannett group.	Tygee sandstone 100 Draney limestone 200 Bechler conglomerate 1, 775 Peterson limestone 205 Ephraim conglomerate 1, 025	3, 305
Jurassic.	Stump sandstone.	Greenish-gray sandstone, with massive calcareous bed at base	200–600
	Preuss sandstone.	Red sandstones and shales	1, 300
	Unconformity		
	Twin Creek limestone.	Whitish shaly limestone, some massive beds	3, 500±
Jurassic or Triassic.	Nugget sandstone.	Subdivided into four members: Red sandstone, with heavy grit at base, succeeded by cherty limestone and red shale. Raymond Canyon section	1, 900
Triassic (Lower Triassic).	Ankareh formation.	Variable, yellow sugary sandstone, thin to massive bedded, or red or chocolate-colored shale and sandstone, or mottled clays and shale with some sandstone and limestone	750±
	Thaynes limestone.	Limestones, calcareous sandstones, and shales	2, 000±
	Woodside shale.	Thin-bedded calcareous shales and limestones	1, 500

THE BECKWITH PROBLEM.

The Beckwith formation has been identified at several localities in western Wyoming and adjacent parts of Idaho by a number of geologists, but present knowledge of the formation is largely derived from the three principal published descriptions, which represent more or less separated districts and contain differences sufficient to warrant a brief discussion. Their main features are set forth in the following table, which includes also the correlations given in the present report:

[1] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, pp. 406–416, 1913.

Tentative correlation of the Beckwith and Bear River formations in southeastern Idaho and southwestern Wyoming.

Age.	Southeastern Idaho (Mansfield and Roundy).	Idaho-Wyoming border (Breger, U. S. Geol. Survey Bull. 430, pp. 562–563, 1910).	Southwestern Wyoming (Veatch, U. S. Geol. Survey Prof. Paper 56, pp. 57–61, 1907).		Lincoln County, Wyo. (Schultz, U. S. Geol. Survey Bull. 543, pp. 30, 52–55, 1914).
Upper Cretaceous.	Not recognized.		Bear River.		Bear River. Unconformity——
			Western area.	Eastern area.	
Cretaceous (Lower Cretaceous?).	Wayan formation: *Feet.* Alternating sandstone and shales .... 9,000 Sandstones, shales, and limestones 2,800	Higher beds not recognized.	Beckwith: Upper member time equivalent of Lower Cretaceous and Dakota (?); consists of light-colored sandstones and clays; 3,000 feet.	Beckwith: Upper and lower phases merge. Predominant reddish color but all light color; conglomerates in this section are white to yellow. Entire section about 4,000 feet.	Not represented or included with Bear River.
Unconformity—— Cretaceous (?).	Gannett group: Tygee sandstone .... 100+ Draney limestone .... 200 Bechler conglomerate ... 1,775 Peterson limestone ...... 205 Ephraim conglomerate .. 1,025	Beckwith: *Feet.* Upper gray limestone .. 100 Conglomerate 850			
Jurassic.	Stump sandstone .... 200–600 Preuss sandstone .... 1,300 Unconformity——	Lower gray band sandstone ...... 250–600 Red sandstone 1,200	Beckwith: Lower red-bed member composed of sandy clays, sandstones, and conglomerates; 2,500 feet; Upper Jurassic.	Beckwith: Lower part of section.	Beckwith considered equivalent of Veatch's eastern section, but all Jurassic. Light-colored shale, sandstone, and clay with associated beds of white to light-yellow and red conglomerate and black limestone; 900–2,400 feet.
	Twin Creek limestone.	Twin Creek.	Twin Creek.	Twin Creek.	Twin Creek.

Veatch,[1] who defines and describes the formation, divides it into two unnamed members—"a lower red-bed member composed of interbedded sandy clays, sandstones, and conglomerates 2,500 feet thick, and an upper member composed of rather light-colored interbedded sandstones and clays with a thickness of 3,000 feet or more." In the eastern exposures within his district these two phases merge. "Just west of Hilliard these beds, while having a predominant reddish cast, are all light in color. The conglomerates, which near Beckwith are deep red, are here white to yellow." Veatch appears not to have found fossils in the Beckwith, but he refers to this formation collections of marine Jurassic fossils previously made by Stanton at two localities, one of which was outside of the district described. On the evidence of these fossils he refers the lower part of the Beckwith to the Jurassic; the remainder, he thinks, "contains time equivalents of the Lower Cretaceous and Dakota."

Breger [2] gives the following account of the Beckwith formation in the Crow Creek region, Idaho, which is included in the Montpelier and Wayan quadrangles:

> This formation consists of red sandstone and conglomerates with two conspicuous gray bands. The lower gray band is a dark greenish-gray calcareous sandstone 250 to 600 feet thick and occurs 1,200 feet above the base of the formation. The lower 1,200 feet consists of red sandstones and shales, apparently without conglomerates. The conglomerates seem to be confined * * * to the interval above the lower gray band, constituting most of the rocks for a thickness of 850 feet. They are succeeded by the second or upper gray band, a massive limestone, more or less marly and light blue-gray in color. This rock attains a thickness of 100 feet in Stump Canyon and northward, where it forms a resistant ledge that may easily be traced by its light color.

Breger makes no mention of fossils in the formation.

Schultz [3] describes the formation as it occurs in Lincoln County, Wyo., south of Snake River and east of the Salt River Range and the Absaroka Ridge. There it represents the

> direct northward extension of the Beckwith formation of the eastern belt of Uinta County [Veatch's area], where the conglomerate phase merges with the upper sandstone and shale. * * * The beds are composed of light-colored shale, sandstone, and clay. The sandstone is usually light yellow, pink, or white, and the clay varies from yellow or light pinkish red to dark purple. With the sandstone, shale, and clay are associated beds of white to light yellow and red conglomerate and black limestone. In places * * * conglomerate beds constitute an important part of the formation.

Fossils are not numerous, but Schultz obtained collections from four localities. These were examined by Stanton, who referred three of the collections to the Jurassic and stated that the fourth was not sufficient for age determination but suggested Jurassic. According to Schultz two of the lots "come from the top of the Beckwith and indicate that it is Upper Jurassic." The thickness of the formation in the region ranges from 900 to 2,400 feet.

Lithologically the descriptions given by Veatch and Schultz agree fairly well, except that in Schultz's area the red conglomeratic phase seems not to be well developed. In both areas sandstones and clays predominate in the formation. Conglomerates appear to be of relatively minor importance. Veatch makes no mention of limestone, but Schultz refers to beds of black limestone. Breger, on the other hand, does not mention clays, but emphasizes two gray bands, one of sandstone and the other of limestone, with an intermediate massive conglomerate. He also notes the presence of a thick band of red sandstones and shales below the lower gray band. Thus he divides the formation into a series of bands which, he says, "maintain these characters throughout the area covered by the present reconnaissance, * * * a distance of about 35 miles." The formation in the Wyoming region appears to be more variable, and the subdivisions noted by Veatch and Schultz do not appear to continue over considerable areas.

The study of the Wayan and Montpelier quadrangles has given the writers an opportunity to review in some detail Breger's work on the Beckwith and to cover a somewhat larger area than he examined. They have also seen the Beckwith northeast and southeast of Evanston, Wyo., but have not been able to make extended observations there. In the Idaho region they recognized the four bands described by Breger and found three additional higher ones, but in the portions of the Wyoming Beckwith seen they did not observe any similar arrangement. Perhaps the most striking differences noted in the two regions were the

[1] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 57-58, 1907.

[2] Breger, C. L., The salt resources of the Idaho-Wyoming border, with notes on the geology: U. S. Geol. Survey Bull. 430, pp. 562-563, 1910.

[3] Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 30, 53, 54, 1914.

greater abundance of conglomerates and limestones and more intense red color in the Idaho area contrasted with the predominance of sandstones and clays of lighter colors in the Wyoming area.

Faunally there are several differences to be noted. Veatch refers the lower part of the Beckwith to the Jurassic, but there is an element of doubt in this reference, because of the possibility that the fossils collected earlier by Stanton may have come from unrecognized in-faulted Twin Creek beds, although Veatch does not regard this as probable. The upper beds he considers Cretaceous. Schultz found Jurassic fossils in the top of the Beckwith in his area, and yet he regards the formation there as the direct northward continuation of Veatch's combined section. In the Idaho area the writers found marine Jurassic fossils just at the base of Breger's lower gray band, but the limestone beds higher in the section contain a fresh-water fauna that is thought by Stanton to be later that Jurassic, having affinities with those of the Kootenai and Bear River formations. Nothing comparable to this fresh-water fauna has yet been reported from the other Beckwith areas.

Schultz,[1] from work in Wyoming and Utah, the results of which have not yet been published, has come to look upon the Beckwith as a group rather than a single formation. It is thus seen that the term Beckwith as now used has no very definite meaning, that it is applied to widely varying beds, some of which may not be closely related, and that it probably covers beds belonging to two great systems.

The writers have found it practicable to subdivide the beds hitherto called Beckwith in the Wayan and Montpelier quadrangles into seven formations, two Jurassic and five Cretaceous (?). In view of the above discussion it seems unwise to retain the name Beckwith for any of these formations and new names are therefore assigned. Detailed descriptions of the formations are given on pages 82–83.

THE BEAR RIVER PROBLEM.

The Bear River formation early attracted attention because of its numerous and well-preserved fossils. It was named by Hayden[2] in 1873, but its true stratigraphic position was not determined until nearly 20 years later by Stanton.[3] In 1895 White[4] gave a full description of it, summarizing the information available at that date. Since then other geologists have contributed additional details. (See table on p. 80.)

Although the stratigraphic position of the Bear River has been determined, its relations to the underlying formations are not everywhere clear. It is probable that in some of the earlier accounts strata now assigned to the Beckwith have been included in the Bear River. The formation has not been recognized outside of the region which extends from Old Bear River City, about 9 miles southeast of Evanston, Wyo., northward through the Wyoming and Salt River ranges into the northeastern part of Idaho.[5]

In the Yellowstone Park and extending northward into Canada there is a thick and extensive nonmarine formation, the Kootenai, of Lower Cretaceous age, between which and the Bear River there are certain affinities, but the relations of the two formations to each other are not known. In Idaho and Wyoming there are great thicknesses of strata which have been assigned to the Bear River but in which none of the characteristic Bear River fossils have been found. Stanton[6] comments as follows on a collection made by Schultz on the west flank of the Caribou Range about 2 miles east of Herman. Idaho:

> In my opinion this fauna is Cretaceous, but on account of the absence of definitely characteristic forms I am unable to determine whether it belongs to the Bear River formation. Similar imperfect fossils have been collected in Montana in rocks that are provisionally referred to the Kootenai formation.

The assignment of these and other doubtful beds to the Bear River seems to have been based partly on lithologic resemblances and partly on the actual occurrence in higher beds of characteristic Bear River fossils, as in parts of Lincoln County, Wyo.,[7] and of Bonneville

[1] Personal communication.

[2] Hayden, F. V., U. S. Geol. Survey Terr. Second Ann. Rept., pp. 91–92, 1873.

[3] Stanton, T. W., The stratigraphic position of the Bear River formation: Am. Jour. Sci., 3d ser., vol. 43, pp. 98–115, 1892.

[4] White, C. A., The Bear River formation and its characteristic fauna: U. S. Geol. Survey Bull. 128, 1895.

[5] Veatch, A. C., op. cit., p. 60.

[6] Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, p. 275, 1913.

[7] Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 54–59, 1914.

and Fremont counties in Idaho, north and northeast of the Wayan quadrangle.[1]

The rocks in typical exposures of the Bear River formation may be described as dark shales with calcareous bands and some soft gray sandstones, which are abundantly fossiliferous. A single section which may be regarded as representative may be quoted from Stanton's section on Stowe Creek,[2] near the type locality.

Part of Stanton's section on Stowe Creek, Wyo.

	Feet.
5. Bear River formation:	
Brown sandstone; dip 75° E	20
Soft gray shale	25
Gray sandstone	10
Dark shale	60
Brown sandstone	10
Dark shale with calcareous bands containing numerous fossils: *Pyrgulifera humerosa, Corbula pyriformis, Unio belliplicatus*	250
Sandstone	10
Dark shales with thin bands of limestone and sandstone and occasional carbonaceous seams; many Bear River fossils	400
Gray sandstone; dip 75° E	10
Soft shales	25
Gray sandstone; dip 75° E	20
	840

In some places the shales are sufficiently carbonaceous to carry thin seams of coal, but the coal is generally too poor to be of economic importance.

At a few localities in the Wayan quadrangle there are dark shales with calcareous bands in supposed Bear River strata, but these are not very fossiliferous, and such fossils as occur are not typical of the Bear River. The strata include two rather prominent sets of limestone beds, with which more or less dark shale is interbedded, and great thicknesses of sandstones and shales, some of which are of an intense red color. Lithologically there is no very close agreement between the rocks of the Wayan quadrangle and the typical Bear River, and faunally the relationship is uncertain.

The Kootenai of Canada and Montana contains some coal beds of economic importance. In the Cascade coal basin of Alberta the formation includes some 2,800 feet of sandstones and shales with many valuable coal seams, there being in one locality as many as 14 beds that are possibly workable.[3] In the Philipsburg quadrangle, Mont.,[4] the Kootenai formation includes 1,500 feet of variegated beds, chiefly sandstones and shales with some limestones and conglomerates. The "gastropod limestone"[5] in that quadrangle is physically much like the limestones of the supposed Bear River in the Wayan quadrangle. It is described as a pure gray limestone rich in fossils, chiefly fresh-water snails. The limestones form distinct beds which are separated by shales and crop out as reefs. On fresh fracture the rock is dark gray; on the weathered surface, pale bluish gray. The texture is coarse and less compact than that of the lower limestone. The rock is crowded with spiral shells which are conspicuous on weathered surfaces. The calcareous shale interbedded with and overlying the gastropod limestone is partly of an olive-green, ocherous-weathering type. It grades into sandstones. The uppermost beds consist of more or less calcareous shale, gray to nearly black on fresh fracture but weathering to blue-gray or brown; these beds virtually grade into limestone. The limestones of the supposed Bear River in the Wayan quadrangle occur in the same manner as in the Kootenai of the Philipsburg quadrangle, but they are not so fossiliferous nor so coarse-textured, and the interbedded shales are usually dark gray to blackish, although the olive-green color and gradation to sandstone have been noted.

Other lithologic similarities exist between the so-called Bear River of the Wayan quadrangle and the Kootenai of the Philipsburg quadrangle and other parts of Montana. There are also many differences, among them being the absence of workable coal in the Wayan quadrangle. However, the shales are in some places carbonaceous, and near Auburn, Wyo., a tunnel some 40 feet long has been driven at a coal prospect from which a few lumps of usable coal have been taken.

No recognizable flora has been found in the Wayan "Bear River," but undeterminable stem fragments have been taken from some of the olive-yellow sandstones above the band of

[1] Unpublished data collected by E. G. Woodruff and A. R. Schultz.

[2] Stanton, T. W., The stratigraphic position of the Bear River formation: Am. Jour. Sci., 3d ser., vol. 43, p. 106, 1892.

[3] Dowling, D. B., Report on the Cascade coal basin, Alberta, p. 8, Canada Geol. Survey, 1907.

[4] Calkins, F. C., and Emmons, W. H., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, p. 77, 1913.

[5] Idem, pp. 77-79.

dark shale in the lower part of the formation, and some pieces of dark silicified wood have been found in dark-gray sandstone beds close to the top of the section studied.

From the above descriptions it is clear that the differences between the Wayan "Bear River" and the typical Bear River are so great as to make the correlation of the two formations questionable. On the other hand, the agreement between the beds of the Wayan area and the Kootenai is perhaps not sufficiently close to warrant correlation with that formation until such a correlation is supported by further and more detailed studies. It seems likely that when the detailed stratigraphy of the region north of the Wayan quadrangle, beyond Snake River, is better known the formation will be found to grade upward into the typical Bear River. If the interesting suggestion that the formation should be correlated with the Kootenai of Montana should be substantiated, it might then be possible to determine the stratigraphic relations of the Kootenai and the Bear River.

In the meantime it seems undesirable to apply either term to the formation now called Bear River in the Wayan quadrangle. To avoid ambiguity these beds are named the Wayan formation. The great thickness of the formation, more than 11,800 feet, neither top nor bottom being exposed, and the arrangement of the strata suggest that it may be subdivided later, but this seems inadvisable until detailed studies have been carried farther north. A more detailed description of the formation is given on pages 83–84.

THE FORMATIONS.

PREUSS SANDSTONE.

The Preuss sandstone is named from Preuss Creek, in the northeastern part of the Montpelier quadrangle, about 12 miles northeast of Montpelier. With higher formations it occupies a synclinorium extending northward from the northeastern part of the Montpelier quadrangle completely across the Wayan quadrangle. The eastern extension of the southern part was not traced, but the central and northern parts probably do not extend far east of the area studied.

The formation consists of very fine, even-grained sandstones ranging in color from pale reddish gray to deep dull red. The sandstone is usually calcareous and more or less argillaceous, becoming very shaly in some places. The beds are generally less than 6 inches thick, weather to a dull-red soil, and make the slopes of subordinate ridges. A graphic measurement at the head of Thomas Fork valley gives a thickness of 1,300 feet.

A minor unconformity separates the Preuss sandstone from the underlying Twin Creek limestone.

STUMP SANDSTONE.

The Stump sandstone is named from Stump Peak, at the head of the north fork of Stump Creek, about the center of T. 6 S., R. 45 E., Boise meridian (unsurveyed). It consists mainly of thin-bedded gray to greenish-gray fine-grained sandstones which weather into platy fragments about an inch thick. Near the base are some beds of compact calcareous sandstone, locally as thick as 6 feet. The grains are very fine and chiefly of colorless quartz. The rock tends to break with a conchoidal fracture and to ring under the hammer. Fresh surfaces have a steel-gray color, but weathered surfaces appear velvety brown. Instead of ledges these beds commonly form lines of irregularly weathered blocks that at first glance resemble trap rock. At the base is a bed of grit, or coarse-grained sandstone, which contains marine fossils of Jurassic age. The component grains are colorless quartz, with some greenish chloritic material, and the cement is calcareous and grayish. The fresh rock has a slight pinkish cast, and weathered surfaces are decidedly pinkish. This is practically the only bed in the entire formation from which fossils were collected, and the collections it yielded at several localities gave practically the same fauna. Fossils identified by T. W. Stanton were *Ostrea strigilecula* White ?, Rhynchonella ? sp., Camptonectes ? sp., and Pentacrinus sp. A single collection assigned tentatively to the same or nearly the same horizon included Astarte sp., Trigonia sp., and Belemnites sp. According to Mr. Stanton these forms might all be considered as Twin Creek. They are, however, separated from that formation by an unconformity and more than 1,000 feet of unfossiliferous sandstones.

The Stump sandstone is usually resistant to weathering and forms conspicuous ridges, but south of the Halfway House, on the southern edge of the Wayan quadrangle, it forms a valley. The rock there has probably been weakened by fracturing or other structural disturbance.

The essential features of this formation are present throughout the region studied, but the thickness varies from 200 to 600 feet. Plate XIII, *A*, shows a typical exposure of the Stump sandstone.

GANNETT GROUP.

NAME AND GENERAL FEATURES.

The Gannett group is named from the Gannett Hills, which lie in Bannock County, Idaho, and Lincoln County, Wyo., in the eastern part of the Wayan quadrangle, where all the formations of the group are well exposed. The Gannett Hills have been named in honor of the late Henry Gannett, topographer of the Green River division of the Hayden Survey and subsequently an eminent geographer, who did the first topographic work in this region.

The group includes five distinct subdivisions and has a maximum thickness of over 3,300 feet. It rests, with apparent conformity, upon the Stump sandstone. At the top is the Tygee sandstone, gray and even grained, followed by the Draney limestone, gray and compact. Below are the Bechler and Ephraim conglomerates, separated by the Peterson limestone, which is much like the Draney. Shale appears to be nearly absent from the group.

The fossils thus far collected from the Gannett group are not distinctive, but they are apparently later than Jurassic, so that the age of the group is probably Cretaceous.

The group occurs in much the same areas as the Preuss sandstone, but is confined more to the central portion of the synclinorium.

EPHRAIM CONGLOMERATE.

The Ephraim conglomerate, at the base of the group, is named from Ephraim Valley, in sec. 36, T. 10 S., R. 45 E., Boise meridian, which lies in the formation. The rock is a red conglomerate with minor amounts of sandstone and some thin bands of gray to purplish limestone. It is about 1,000 feet thick at the type locality, but varies much in thickness and character, becoming in some regions practically all conglomerate with pebbles, some of which are nearly a foot in diameter. The pebbles represent a wide variety of materials, but perhaps 100 feet above the base there is an olive-yellow band, 25 feet or more thick, in which the pebbles are almost exclusively of dark chert, rounded or subangular, and generally an inch or less in diameter. The Ephraim conglomerate forms most of the mass known as Red Mountain, in the northeastern part of the Montpelier quadrangle, where it is well exposed. (See Pl. XIII, *B*.)

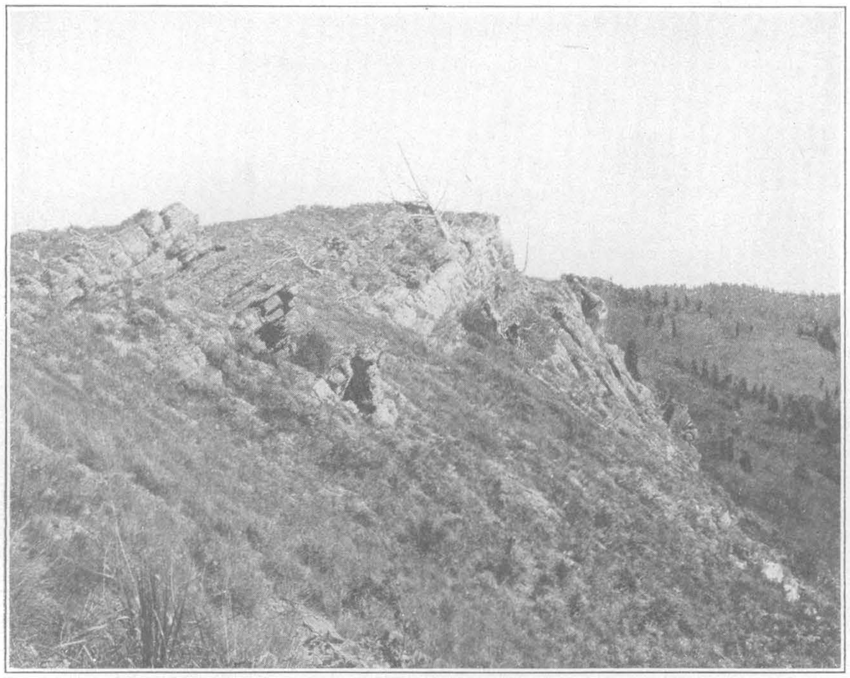
PETERSON LIMESTONE.

The Peterson limestone is named from Peterson's ranch, along Tygee Creek, in sec. 34, T. 7 S., R. 46 E., Boise meridian, east of which the formation is well exposed. It is about 200 feet thick, massively bedded near the top, and very persistent throughout the region studied, forming prominent ridges that can be followed by the eye for miles from some of the higher summits. (See Pl. XIV, *A*.) The following fossils from this limestone have been identified by T. W. Stanton: Unio sp., Planorbis (Gyraulus) sp. related to *P. præcursoris* White, Viviparus sp., Goniobasis? sp., and two distinct species of Physa. Fossils of similar types occur in the Kootenai, Bear River, and later formations. The fresh-water gastropods are not distinctive and similar forms of Planorbis are found in both the Morrison and Bear River, but no species of Physa have been reported from beds older than the Bear River.

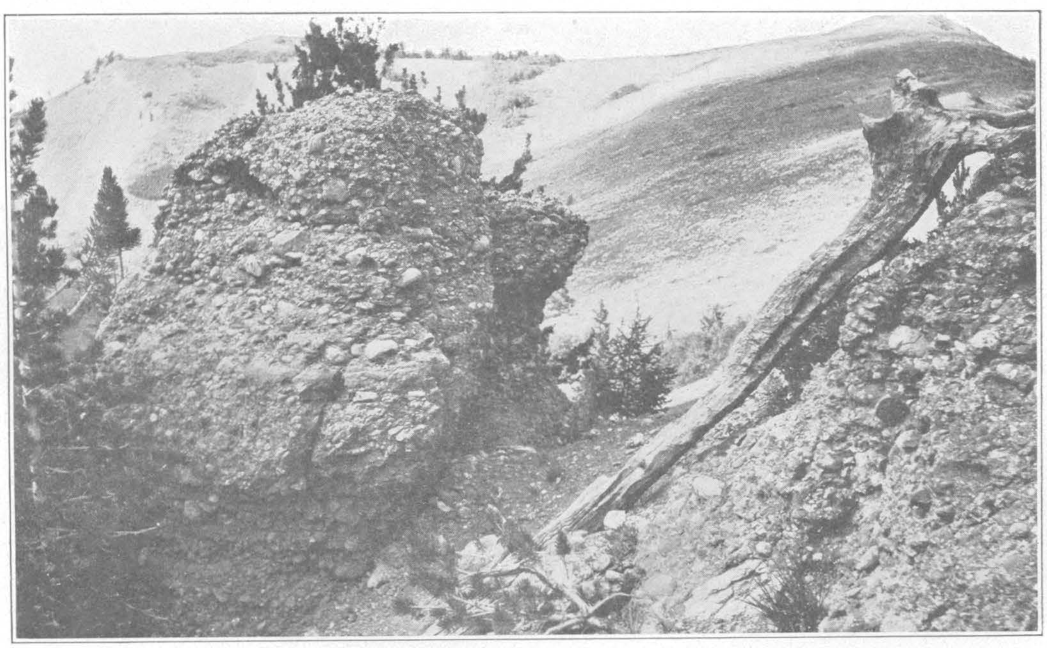
BECHLER CONGLOMERATE.

The Bechler conglomerate is named from Bechler Creek, which enters Stump Creek from the north about a quarter of a mile north of the mouth of Boulder Creek, in T. 6 S., R. 45 E., Boise meridian (unsurveyed), in Bannock County. Bechler Creek is named in honor of G. R. Bechler, topographer of the Teton division of the Hayden Survey, who did the first topographic work in the region adjoining the Wayan quadrangle on the north.

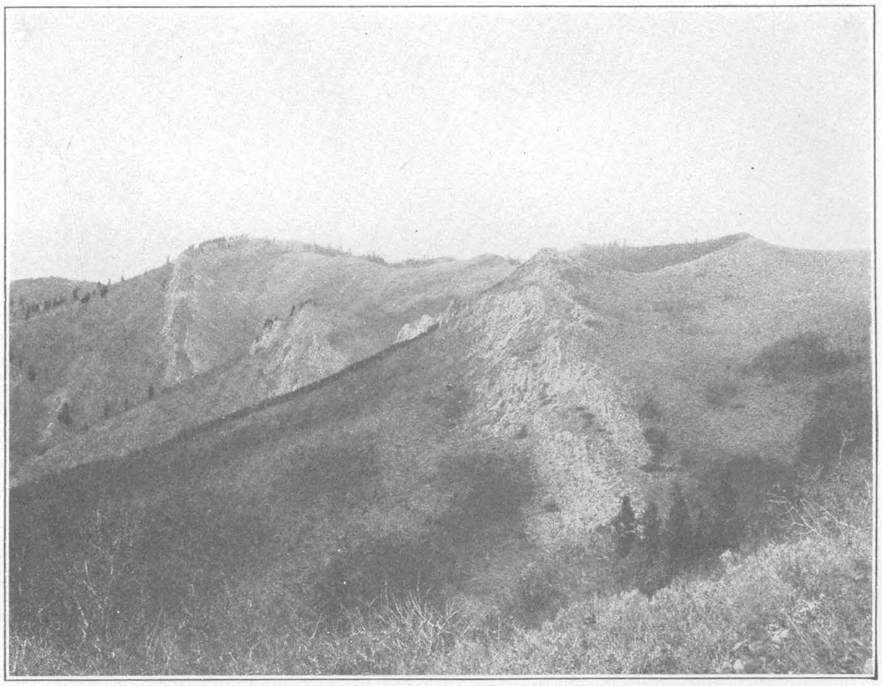
The formation is composed of about 1,700 feet of gray, reddish, and "salt and pepper" sandstones with interbedded conglomerates. The "salt and pepper" color predominates, and there is probably over twice as much conglomerate as sandstone. The proportion of



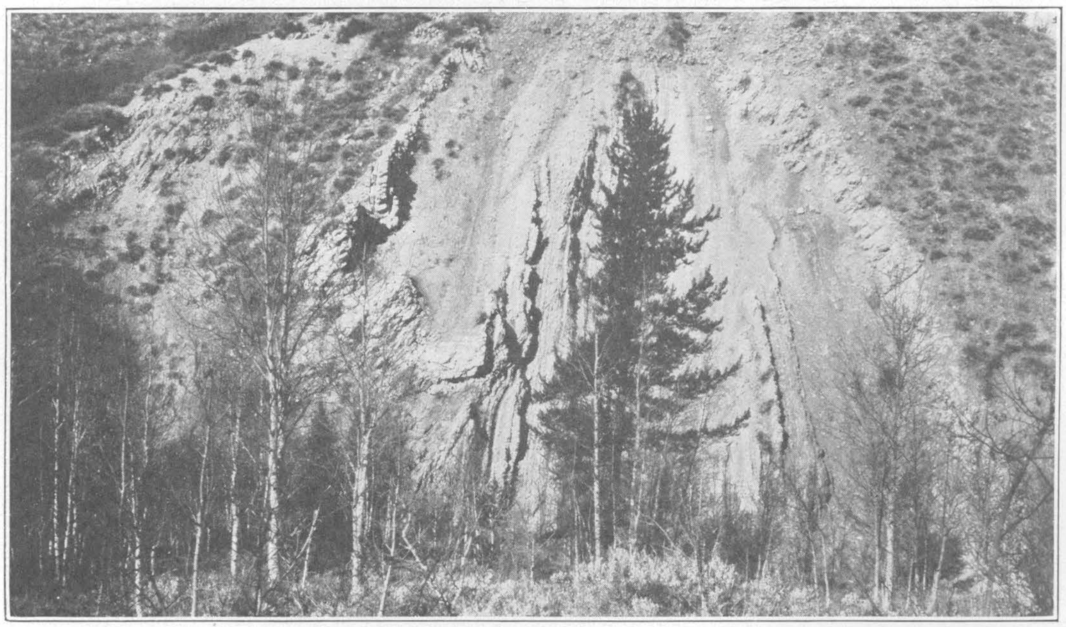
A. VIEW NORTHWEST ALONG THE RIDGE SOUTH OF THE HEAD OF LANES CREEK, IN THE NORTHWESTERN PART OF THE FREEDOM QUADRANGLE, IDAHO.



B. VIEW NORTH NEAR THE SUMMIT OF RED MOUNTAIN, IN THE NORTHEASTERN PART OF THE MONTPELIER QUADRANGLE, IDAHO.



A. VIEW NORTH ALONG THE WEST FLANK OF THE CARIBOU RANGE, IN THE EAST-CENTRAL PART OF THE FREEDOM QUADRANGLE, IDAHO.



B. SHALY AND LIMY STRATA OF THE LOWER DIVISION OF THE WAYAN FORMATION EXPOSED IN TINCUP CANYON, IN THE NORTH-CENTRAL PART OF THE FREEDOM QUADRANGLE, IDAHO.

sandstone, however, is greater than in the Ephraim conglomerate. The pebbles in the conglomerate are small, few having a diameter of more than 1 inch.

DRANEY LIMESTONE.

The Draney limestone is named from the Draney ranch, on Tygee Creek, in sec. 10, T. 8 S., R. 46 E., Boise meridian. The limestone occurs on the top of the ridge about a mile and a quarter east of the ranch. The formation is about 200 feet thick and is fairly massive, the individual beds reaching a maximum thickness of 1½ feet. The rock is much like that of the Peterson limestone, but is not so massively bedded near the top. It is compact and gray, but weathers to a dirty-white color. The following fossils from this limestone have been identified by T. W. Stanton: Unio sp. related to *U. vetustus* Meek, Viviparus? sp., and Goniobasis? sp., a simple smooth form resembling *G:? increbescens* Stanton or *Amnicola? cretacea* Stanton.

TYGEE SANDSTONE.

The Tygee sandstone is named from Tygee Creek, east of which, in T. 8 S., R. 46 E., the formation is well exposed in association with the Draney limestone on the top of the ridge along the Idaho-Wyoming boundary. The rock is gray to buff, even grained, and without the greenish or reddish tinges of some of the higher sandstones. The top is not exposed, and in much of the region this sandstone with part or all of the limestone below it has been eroded before the deposition of the Wayan formation. At the type locality about 100 feet of this sandstone is exposed.

WAYAN FORMATION.

Resting unconformably upon the Gannett group is a group of beds composed of sandstones, shales, limestones, and some conglomerates. Neither the top nor the bottom is known, but apparently about 11,800 feet of beds are exposed. These rocks are confined to the northeastern part of the Wayan quadrangle and the region to the north. The formation is named from the settlement of Wayan, in Bannock County, in the northwestern part of the Wayan quadrangle. It occupies the hills immediately east of Wayan and appears to be broadly divisible into two units, the upper composed chiefly of alternating sandstones and shales with some conglomeratic beds, but without significant limestones, and the lower comprising some eight subdivisions, including several thick beds of limestone.

The lower unit in the section exposed in Tincup Canyon includes four sets of red beds, three of limestone and shale, and one of yellow sandstone. These beds in ascending order may be briefly described as follows:

1. Beneath the limestone of the dome that forms a fine arch about a mile west of the mouth of the South Fork of Tincup Creek there is a suggestion of reddish soil that may represent red beds not otherwise exposed.
2. Gray limestones, weathering whitish, with dark-colored shales. The top 20 feet is rather massively bedded limestone; shale and limestone are interbedded below, the proportion of shale gradually increasing toward the base.
3. Red beds consisting largely of red-weathering soft gray sandstone but including also some gray and red shaly beds and some calcareous beds. These rocks generally form slopes and soil of a light-red color, a brighter color than that of No. 5.
4. Bands of gray limestone in dark shales. Some of the limestone beds are relatively massive, 1½ feet or more thick, and project from the weaker shales.
5. Red beds with purplish to reddish-gray sandstone, massive near the top but in thinner beds and associated with shale below, the whole weathering to a red soil and forming fairly smooth slopes.
6. Dark gray to black shale with massive buff limestone near the top and thinner beds of limestone below. (See Pl. XIV, *B*.)
7. Greenish-gray sandstones and grit, weathering, yellow and reddish, usually forming marked ridges and rough talus slopes of large blocks. The sandstone becomes conglomeratic in places.
8. Red to purplish sandstone with some shaly and some calcareous beds.

Some of these subdivisions may be recognized north and south of Tincup Canyon, but their structure is complex, they appear to vary in lithology and thickness, and they are in places not well expressed topographically. For these reasons it is not yet practicable to map them separately. Their combined thickness is estimated at about 2,800 feet.

The upper unit of the formation, if there is no reduplication by folding and faulting, comprises some 9,000 feet of westward-dipping strata that lie along the upper course of Tincup Creek above the canyon. These beds are chiefly red and gray sandstones, with intervening shales and some calcareous beds. The sandstones form a series of low ridges and points, but the shales are mainly weathered into soil-covered areas. Toward the top yellowish and brownish sandstones appear, and the uppermost strata recognized are shown only by fragments of dark-gray siliceous sandstone and pieces of dark-brown or black silicified wood weathered white.

The upper unit apparently represents the east limb of a broad syncline, the axial region of which is occupied by the layer containing silicified wood. The syncline is broken on the west by a fault. The northward continuation of the strata and the structural relations suggest that higher beds may appear in that direction.

The fossils collected from the Wayan formation have come almost entirely from the limestone bands. The following forms have been identified by T. W. Stanton: Unio? sp., Rhytophorus? sp., Viviparus? sp., Limnæa?, opercula of gastropods, and fragments of fresh-water shells. An unidentifiable fragment of bone has also been found. In his report on the collections Mr. Stanton remarks:

The collections from the Wayan quadrangle fail to show any characteristic species of the Bear River formation, and if the Bear River is recognized there it must be on some other basis than paleontologic correlation. This is also true of the Beckwith formation, for the reason that in its type area the Beckwith has yielded so few fossils that it can not be said to have a characteristic fauna.

The few fossils found in both the Wayan formation and the Gannett group are poorly preserved fresh-water forms belonging to Unio and to small, uncharacteristic gastropods referred to several genera. There are, therefore, marked faunal similarities between the Gannett group and the Wyan formation, and certain beds in both, particularly the limestones, are also lithologically similar. These likenesses sometimes make difficult the distinction between the formations where the similar beds of each occur in proximity, and thus the unconformity between them, though in many places distinct, is locally hard to detect and probably does not represent any great stratigraphic interval.

THE FLORA OF THE FOX HILLS SANDSTONE.

By F. H. Knowlton.

INTRODUCTION.

A knowledge of the land plants of the Rocky Mountain region in Fox Hills time has long been desired, because the Fox Hills sandstone lies between formations that are abundantly plant bearing. As the Fox Hills is a marine formation, it probably nowhere carries the remains of a large land flora, although, as it was evidently deposited near shore in rather shallow water, it doubtless includes some small pockets or deposits in which the remains of land plants may be discovered. Isolated specimens of such plants have been found in the formation at several localities, and the peculiar marine alga Halymenites is at many places abundant in its beds, but never before, so far as I know, have collections so large as those here considered been described and figured.

The type locality of the Fox Hills sandstone is near Fox Ridge, between Cheyenne and Moreau rivers, S. Dak. Its thickness at this place reaches about 325 feet and in near-by areas in North and South Dakota ranges from 25 feet or less to 450 feet. At a few places where the underlying and overlying formations occur and it should theoretically be present it may be entirely absent, as at a locality on Worthless Creek, S. Dak., reported by Calvert.[1] In the Denver Basin in Colorado, according to Eldridge,[2] the formation has a normal thickness of 800 to 1,000 feet, and at only one locality does its thickness fall to 500 feet. Later students of the geology of Colorado have been inclined to reduce its thickness in this region greatly, perhaps to restrict it to little more than the upper 100 feet of the beds it now includes, but according to T. W. Stanton there is no obvious faunal evidence for changing the established line between the Fox Hills and the underlying Pierre shale.

The material on which the following notes are based comes from the Greeley quadrangle, Colo. Part of it was obtained by T. E. Williard, of the United States Geological Survey, during the field season of 1914, at two localities, one, affording the larger collection, on Wildcat Mound, about 2½ miles south of Milliken, and the other on the north side of Thompson Creek about 1¼ miles northeast of Milliken. The matrix in which the plant remains occur is a yellowish-brown, rather coarse sandstone, and the leaves are fragmentary or so curled up that it is difficult to procure perfect specimens. The exact position of the plant-bearing beds in the local section was not determined, though according to Mr. Williard they are probably within 100 feet of the top. They are, however, undoubtedly below beds containing a typical Fox Hills fauna.

In 1915 these localities were visited by T. W. Stanton, who was able to confirm Mr. Williard's observations concerning the stratigraphic relations of the plant-bearing beds. He also obtained additional material about a quarter of a mile east of Mr. Williard's locality northeast of Milliken, but apparently in beds at nearly the same level, about 21 feet below the top of a massive sandstone in the Fox Hills and probably 100 feet below the top of the formation.

The occurrence of fossil plants in this general region in the midst of or at least below well-defined marine beds has long been known, though apparently this is the first material that has been found so well preserved as to permit adequate description. In 1873 Stevenson[3] found abundant plant remains at a locality which must have been the same as or near the one that has afforded the present collec-

[1] Calvert, W. R., Geology of the Standing Rock and Cheyenne River Indian reservations, North and South Dakota: U. S. Geol. Survey Bull. 575, p. 18, 1914.

[2] Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, p. 71, 1896.

[3] Stevenson, J. J., Report on the geology of a portion of Colorado: U. S. Geog. Surveys W. 100th Mer. Rept., vol. 3, p. 406, 1875.

tions. Concerning this locality he wrote as follows:

Following this rock [Cretaceous] down the South Platte River, we find the lower part of the section well exposed for many miles below the junction of St. Vrains Creek and the river. Here, at a horizon above that of the Platteville coals, the exposure is similar to that at Canon City. At the river level are shales, argillaceous and arenaceous, gradually passing upward into a bluish-gray, very friable sandstone, on which rests a red friable sandstone containing many thin layers which are slightly calcareous. Owing to the superior hardness of the calcareous layers this red sandstone, in weathering, assumes eccentric forms similar to those common on Monument Creek and illustrated in Dr. Hayden's reports. The harder layers are richly fossiliferous. Some of them are made up almost wholly of *Halymenites major* Lesquereux, others literally crowded with remains of Mollusca, and one contains many leaves of dicotyledonous plants. The shale section overlies the important coal beds at Platteville and is traceable down the river for a long distance, the dip in that direction being very slight. Near Evans and in the highest portion of the sandstone the layers containing the fucoid alternate with those containing Mollusca, and the leaf bed is underlaid and overlaid by both fucoidal and molluscan layers. Unfortunately the impressions of the leaves are not sharp, and but one specimen was preserved.

As certain of his observations made in 1873 had been called in question, Stevenson revisited the locality in 1878, and the results of this later visit were published in the following year.[1] His observations were confined mainly to the area on the west side of South Platte River between St. Vrain and Thompson creeks, and for several miles up these streams. In low bluffs both north and south of Thompson Creek he noted a sandstone, which, he says,

is bright yellow and for the most part extremely friable, weathering easily and breaking down into loose sand. But at irregular intervals vertically it shows thin layers of darker sandstone, some of which are quite compact, while others are flaggy, though they all resist the action of the weather. * * *

For the greater portion, the soft yellow sandstones are devoid of fossils, but here and there *Halymenites major* Lesquereux occurs, and occasionally one stumbles on a little nest of Ostrea. The harder layers are quite different, many of the more compact being crowded with the Halymenites, while most of the flaggy layers contain Fox Hills fossils, among which are *Ammonites lobatus*, *Nucula cancellata*, *Mactra warreniana*, and numerous other species. Other layers are crowded with fragments of carbonized wood. * * * In 1873 Mr. Kelley discovered a thin layer containing impressions of dicotyledonous leaves. But the leaf specimens, with nearly all the other specimens obtained during that visit, were destroyed by an accident to the building where they were stored in Evans. During my last visit the leaf bed could not be found.

[1] Stevenson, J. J., Note on the Fox Hills group of Colorado: Am. Jour. Sci., 3d ser., vol. 17, pp. 369–373, 1879.

In 1906 the University of Colorado sent out a scientific expedition to the northeastern part of the State under the direction of Prof. Junius Henderson.[2] Considerable collections of fossils were obtained, and among them was a single species of plant found by Prof. Henderson near the mouth of Thompson Creek, just west of Evans. This was described in the same report by Cockerell [3] under the name "Ficus sp. nov.," no specific name being given, as it was very fragmentary. It is undoubtedly the same as that here described as *Rhamnus? williardi.*

As nearly as can be made out the locality described by Stevenson was visited in 1910 by W. T. Lee, of the United States Geological Survey, who was especially interested in studying the relation of these beds to the Platteville coal. Mr. Lee found Fox Hills invertebrates near the top of Wildcat Mound and at several lower horizons in the massive bed of sandstone which overlies a thin bed of coal. He also noted the presence of dicotyledonous leaves, but did not collect specimens.

THE FLORA.

Although the known flora of the Fox Hills sandstone is still small, the importance that attaches to it makes a discussion of its affinities and relations a matter of considerable interest. The following is a list of the forms recognized:

- Halymenites major Lesquereux.
- Anemia sp.
- Equisetum sp.
- Sequoia reichenbachi (Geinitz) Heer.
- Sequoia magnifolia n. sp.
- Cephalotaxus? coloradensis n. sp.
- Podocarpus? stantoni n. sp.
- Myrica torreyi Lesquereux.
- Ficus speciosissima Ward.
- Rhamnus? williardi n. sp.
- Aristolochia? coloradensis n. sp.
- Viburnum vulpinum n. sp.
- Phyllites cockerelli n. sp.

From this list it appears that only four of the named species have been previously known, the remainder being new to science or so fragmentary as not to merit specific designation. These four species are found also in the older beds of the Montana group—that is, in the beds underlying the Fox Hills.

[2] Henderson, Junius, Scientific expedition to northeastern Colorado: Colorado Univ. Studies, vol. 4, p. 151, 1907.

[3] Cockerell, T. D. A., A new plant (Ficus) from the Fox Hills Cretaceous: Idem, p. 152.

Thus *Halymenites major*, while most abundantly and characteristically developed in the Fox Hills sandstone, occurs also at a number of places in older beds of the Montana group, and even in still older beds of late Colorado age. It also occurs sparingly, generally in reduced size, in the Cannonball marine member of the Lance formation, which overlies the Fox Hills. *Sequoia reichenbachi* has a very wide range in age, extending from the Upper Jurassic to the Upper Cretaceous; it is especially abundant in the Judith River formation of the Montana group. *Myrica torreyi* is most abundant and widely distributed in the Montana group, but it is also found in the Laramie and rarely in post-Laramie beds. *Ficus speciosissima* belongs to a group of closely related forms that range in age from Montana to post-Laramie, but as at present known the species occurs only in beds of the Montana group.

The form here described under the new name *Sequoia magnifolia* was previously known from a locality recorded as "10 miles northeast of Greeley," which would be in the Laramie area, but there is now strong presumptive evidence that the species occurs only in the Fox Hills sandstone. The Greeley specimen has affinity with a form of Montana age. The two new species referred to Cephalotaxus and Podicarpus have no very close relationship with forms already described, though in some particulars they agree with species from the older Cretaceous. The species of Rhamnus, which is the most abundant form in the collections except the Halymenites, agrees in certain characters with *Rhamnus elegans* Newberry, a species supposed to come from the Laramie, but on the whole the two are very distinct. The Aristolochia is not recognized as having any very close relatives. The Viburnum belongs to a small group of species that range from the Upper Cretaceous into the lower Eocene, but it is easily separated from the others of this group. The fragment of a fern (Anemia) resembles several well-known Upper Cretaceous forms, but it is so small as to be of little value.

From the foregoing review it appears that this little Fox Hills flora shows distinctly Upper Cretaceous affinities, being, as might be presumed from its stratigraphic position, intermediate between the older floras of the Montana group and the younger flora of the overlying Laramie but having a preponderance in its resemblances to the Montana. There is very little to indicate relationship with floras of formations younger than the Laramie—that is, the Lance, Fort Union, and others—but the number of species is still far too small to be made the basis of any very extended generalization.

Ecologically this flora appears to indicate a much more abundant supply of moisture than now exists in the region, though this should naturally follow from the known fact that it must have been growing near the sea, and not far above sea level. The meager data appear to indicate a warm-temperate climate.

Descriptions of the species are given below.

Halymenites major Lesquereux.

Halymenites major Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, pp. 373, 390, 1873; The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 38, pl. 1, figs. 7, 8, 1878.

This is undoubtedly the most abundant and characteristic plant of the Fox Hills sandstone, in which it has for many years been known to occur. It is, in fact, so uniformly present in this formation that it is almost diagnostic, though not quite, for it has been found in comparative abundance in beds as old as the Colorado and more sparsely in beds younger than the Fox Hills. It is most abundant in the Fox Hills strata, however, and perhaps grew in a greater degree of perfection during Fox Hills time. At certain localities on Cannonball River and elsewhere in North Dakota countless thousands of specimens have been noted, and it is said to be almost or perhaps quite as numerous at some places in Colorado.

Anemia sp.

Plate XV, figures 6, 7.

The collection from Wildcat Mound contains two minute fragments of a fern that with little doubt belongs to the genus Anemia. As may be seen from the enlarged figures, they probably represent only fragments of lateral divisions of a comparatively large frond. They are cut deeply into linear, sharply toothed, rather obtuse segments. The nervation is obscure.

Occurrence: Wildcat Mound, 2½ miles south of Milliken, Colo.; collected by T. E. Williard.

Equisetum sp.

Plate XVIII, figure 2.

The specimen here figured is the only one in the collections that can reasonably be referred to Equisetum, and it is so small a fragment that under ordinary circumstances it would not be worthy of mention. It appears to represent the basal part of a segment of a stem pulled out of the sheath. It is about 2 centimeters in length and seems to have been nearly 1 centimeter in diameter. It is very strongly ribbed, the number of ribs, so far as can be made out, being about 12 or 14. It is so fragmentary that any comparisons between it and described species would likely be misleading, and it is left for future exploration to establish its validity.

Occurrence: Wildcat Mound, 2½ miles south of Milliken, Colo.; collected by T. E. Williard.

Sequoia reichenbachi (Geinitz) Heer.

Sequoia reichenbachi (Geinitz) Heer, Flora fossilis arctica, vol. 1, p. 83, pl. 43, figs. 1d, 2b, 5a, 1868.

This species is one of the most abundant and widely distributed forms known in this country, ranging in age from Upper Jurassic to Upper Cretaceous and in geographic distribution from the Atlantic to the Pacific. It is especially abundant and well developed in the Montana group, particularly in the Judith River formation, where it is in many places more numerous in individuals than all the other forms combined. Its presence in the Fox Hills sandstone is therefore not a matter of surprise.

Occurrence: Wildcat Mound, 2½ miles south of Milliken, Colo.; collected by T. E. Williard.

Sequoia magnifolia n. sp.

Plate XV, figures 1–3.

Sequoia longifolia Lesquereux, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 79, pl. 7, figs. 14, 14a [not pl. 61, figs. 28, 29], 1878.

Geinitzia longifolia (Lesquereux) Knowlton, U. S. Geol. Survey Bull. 152, p. 28 [in part], 1898.

There appears to be some confusion regarding Lesquereux's *Sequoia longifolia*. So far as can be made out, Lesquereux had specimens of a long-leaved conifer from Black Buttes, Wyo., to which it is inferred he gave the manuscript name *Sequoia longifolia*. Before this name was published, however, specimens thought to represent the same form were obtained from Point of Rocks, Wyo., and the name was first published in 1876,[1] under the designation "*Sequoia longifolia* Lesq., MSS." In explanation Lesquereux adds: "This species was already described from Black Buttes specimens." I can not find that the name was ever published in connection with descriptions of the Black Buttes specimens, and it seems that when Lesquereux's description of the Black Buttes material was first published he changed the name of the long-leaved conifer noted at that place to *Sequoia acuminata*.[2] It is certain that he nowhere definitely recorded *Sequoia longifolia* as coming from Black Buttes, nor has it since been found there.

If the above interpretation is correct, it establishes Point of Rocks, Wyo., as the type locality for *Sequoia longifolia* and excludes Black Buttes. The type specimens are the originals of figures 28 and 29 of Plate LXI of Lesquereux's "Tertiary flora" and are Nos. 73 and 74, respectively, of the United States National Museum collections. This disposition, however, leaves the specimen shown under this name in figures 14 and 14a of Plate VII of the "Tertiary flora" still to be accounted for. This specimen is said by Lesquereux to have come from the "Haley coal mine, 10 miles northeast of Greeley, Colo. (A. C. Peale);" it is No. 61 of the National Museum collections. I was informed by Dr. Peale that this statement, so far as he was concerned, is in error, for he did not obtain the specimen and in fact was never at this locality. Inasmuch as Lesquereux points out certain marked differences between the Point of Rocks and Greeley specimens and adds "It may be, therefore, that these specimens represent different species," it seems justifiable to restrict the name to the Point of Rocks specimens and such others as may be identified with them, and to consider the Greeley specimen as entitled to separate standing.

Up to the present time, however, the Greeley specimen has remained unique and the exact locality has not been identified. According to

[1] Lesquereux, Leo, On the Tertiary flora of the North American Lignitic: U. S. Geog. and Geol. Survey Terr. Rept. for 1874, p. 298, 1876.

[2] Lesquereux, Leo, On some new species of fossil plants from the Lignitic formations: U. S. Geol. and Geog. Survey Terr. Bull., 2d ser., No. 5, p. 384, Jan. 8, 1876.

the geologic map of Colorado by R. D. George, published in 1913, a point 10 miles northeast of Greeley would be in an area of the Laramie formation, but now for the first time specimens that can not be distinguished from the type have been obtained in the Fox Hills sandstone about this distance southwest of Greeley. Whether there is any significance in this circumstance is impossible to say, but the species has not been recognized in the extensive recent studies of the plants of the Laramie in the Denver Basin, and it is, to say the least, uncertain as to whether the Greeley specimen came from the Laramie or the Fox Hills.

The material here described, which was obtained within about 100 feet of the top of the undoubted Fox Hills, consists of a dozen or more specimens of branches and branchlets and two or three cones. It is all more or less fragmentary, the three specimens here figured being the best. The one shown in figure 2 is indistinguishable from the original Greeley specimen. It is a branch about 8 centimeters in length and 3 millimeters in diameter. The leaves are broad, linear, rather abruptly narrowed to the base, acuminate at the apex, and 2.5 to 3 centimeters in length. The specimen shown in figure 3 is 13 centimeters long and shows the raised bases of the leaves. The cone (fig. 1) is very fragmentary, but so far as can be made out it is oblong, the long diameter being about 4.5 centimeters and the short diameter about 2.5 centimeters. Another specimen, too poorly preserved to figure, is very instructive. It is a thick leafy branch about 7 centimeters long bearing at the apex a cone that appears to be of about the same size as the one here figured.

As indicated in the synonymy, Lesquereux's *Sequoia longifolia* was at one time transferred to the genus Geinitzia, but the position and character of the cones above described undoubtedly preclude this reference, for they are not at all the cones of Geinitzia.

For the reasons set forth above, a new name has been given to the original Greeley specimen and the specimens from the Fox Hills sandstone identified with it.

Occurrence: About 1 mile northeast of Milliken, Colo., in the SE. ¼ NW. ¼ sec. 1, T. 4 N., R. 67 W.; probably within 100 feet of top of the Fox Hills sandstone; collected by T. W. Stanton, July, 1915.

Cephalotaxus? coloradensis n. sp.

Plate XV, figure 4.

Branchlets relatively slender, strongly marked by the leaf bases; leaves apparently arranged spirally but disposed in a single plane by torsion of the petioles; leaves linear-lanceolate, rather abruptly narrowed at the base to a short petiole, narrowly acuminate at the apex; veins three, slender.

Although there are several specimens evidently belonging to this form, they are all so fragmentary that it is difficult if not impossible to formulate a satisfactory description of it. The best specimen is the one figured, and this is only a fragment of a branch or branchlet 5 or 6 centimeters long and showing not more than six leaves. The stem is rather slender for the size of the leaves, though the leaf bases are prominent. The leaves are about 4 centimeters long and about 4 millimeters broad; there seem to be three nerves or veins, though apparently the specimens show the upper side of the leaves, and possibly each leaf has a single strong midrib which, when pressed down and viewed from the upper side, makes it appear to be three-ribbed.

The generic reference is uncertain and has been questioned. The specimens appear to approach the living Cephalotaxus most closely, but it will require more and better-preserved material to settle the question with certainty.

Occurrence: About 1 mile northeast of Milliken, Colo., in the SE. ¼ NW. ¼ sec. 1, T. 4 N., R. 67 W.; collected by T. W. Stanton, July, 1915.

Podocarpus? stantoni n. sp.

Plate XV, figure 5.

Leaf evidently very thick and leathery in texture, narrowly lanceolate in shape, slightly narrowed below to a broad, apparently sessile base, apparently acuminate at the apex; nerves five, the middle one a little stronger than the others, slightly converging in the apical portion, outer pair smallest, running into the margin about three-fourths the length from the base; space between the nerves finely and irregularly wrinkled.

This form is represented only by the specimen figured, which is a detached leaf now 8.5 centimeters long, but it lacks the apex, which would probably make the length about 10 centimeters when complete. The width is nearly 2 centimeters at the broadest point, not far above the base. The leaf has the appearance of having been sessile and attached by nearly half the width, but it is slightly broken at this point and it may have had a short petiole.

It is unfortunate that this form must be described from a single detached leaf, for an error in interpretation is thus easily possible. The apex and point of attachment can not be determined with absolute certainty, and this may mean much or little in its correct allocation. This leaf appears to be referable to the genus Podocarpus in its broad application, or better to the section Nageia, which is sometimes accorded separate generic rank. Thus, in general appearance this leaf strongly suggests *Nageiopsis longifolia* Fontaine,[1] from the Potomac group of Virginia and Maryland, though the latter differs markedly in having a short, slightly twisted petiole, 9 to 12, usually 10 nerves or veins, and noncoriaceous leaf substance. In discussing the genus Nageiopsis Berry writes as follows:

> The diagnostic characters which deserve emphasis are the branching habit, the persistent leaves, and the small veins, which do not converge to any great extent in the apex of the leaf. All these serve to distinguish the species of Nageiopsis from the cycadaceous fronds or leaflets with which they are most likely to be confused.

In view of the incompleteness of the material I have decided to refer it to the genus Podocarpus with the query, and to wait until better collections are obtained before fixing its position more definitely. It is believed to be sufficiently well characterized in the above description and figure to permit subsequent recognition.

Occurrence: About 1 mile northeast of Milliken, Colo., in the SE. ¼ NW. ¼ sec. 1, T. 4 N., R. 16 W.; collected by T. W. Stanton, July, 1915.

Myrica torreyi Lesquereux.

Plate XVII, figure 7.

Myrica torreyi Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 292, 1873; The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 129, pl. 16, figs. 3-10, 1878.

This species was first recorded from Black Buttes, Wyo., where it was found in beds then and long afterward regarded as of Laramie age but believed by me to be slightly younger than Laramie. Later, however, it was found that this species was fairly abundant and widely distributed in the beds of the Montana group, occurring, for instance, at Point of Rocks, Wyo., and in the Vermejo formation at Rockvale, La Veta, and Walsenburg, Colo. It is also present in the Laramie of the Denver Basin, having been found on Crow Creek about 25 miles southeast of Greeley, Colo.

The only example noted in the present collections is the fragment figured, which is a segment from the upper portion of what appears to be a normal leaf of the species.

Occurrence: Wildcat Mound, 2½ miles south of Milliken, Colo.; collected by T. E. Williard.

Ficus speciosissima Ward.

Plate XVI, figure 3.

Ficus speciosissima Ward, U. S. Geol. Survey Sixth Ann. Rept., p. 552, pl. 45, fig. 1, 1886; U. S. Geol. Survey Bull. 37, p. 39, pl. 21, fig. 3, 1887.

The collection contains several leaves of this form, the large one figured being not only the most perfect one but the most complete leaf in the whole collection. It is believed to be a small leaf of Ward's *Ficus speciosissima*, differing in being slightly broader in proportion to the length and not so deeply heart-shaped at the base. The nervation is of precisely the same type in both, except as regards the basal tertiaries.

The specimens also resemble an unnamed species of Ficus from the Vermejo formation of southern Colorado and adjacent parts of New Mexico, but the latter is still smaller and differs in a number of minor particulars. They are also very much like what Lesquereux [2] called *Ficus planicostata latifolia*, from Black Buttes, Wyo.—in fact, they hardly differ except in size, the Wyoming leaf being considerably smaller. It thus appears that there are several forms to which different names have been given but which differ only in minor particulars, and it seems quite possible that study of a considerable number of each form, if they can be procured, will show that they should be combined into a single species. For the present, however, it seems best to keep them apart, and on account of the stratigraphic position of the leaves under consideration they are regarded as small

[1] Cf. Berry, E. W., Maryland Geol. Survey, Lower Cretaceous, p. 384, pl. 61, 1911.

[2] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 202, pl. 31, fig. 9, 1878.

specimens of *Ficus speciosissima*, slightly broader and less distinctly heart-shaped than the type.

Occurrence: Wildcat Mound, 2½ miles south of Milliken, Colo.; collected by T. E. Williard and T. W. Stanton.

Rhamnus? williardi n. sp.

Plate XVI, figures 1, 2; Plate XVII, figures 1–4.

Ficus sp. Cockerell, Colorado Univ. Studies, vol. 4, p. 152, 1907.

Leaves very thick in texture, ovate-lanceolate, slightly unequal-sided, rather abruptly rounded below to an almost truncate base, very gradually narrowed above to an acuminate apex; margin perfectly entire; petiole very strong; nervation exceedingly strong, consisting of a thick, perfectly straight midrib, and some 15 pairs of nearly as strong secondaries, which arise at an angle of about 45°, curve slightly upward, and are camptodrome, each usually curving just inside the margin and joining the one next above; nervilles very numerous, strong, mainly percurrent, and approximately at right angles to the secondaries, with finer nervilles dividing the areas between the main nervilles into quadrangular areolæ. Length about 12 to 14 centimeters; maximum width, not far above the base, about 5 centimeters, though there are several leaves hardly more than 4 centimeters wide. The petiole is at least 2 centimeters long, but it is broken at this point and there is of course no means of knowing how much longer it was. On the upper side of the leaf the midrib and secondaries and even some of the nervilles are very deeply impressed, and on the under side they stand out in strong relief.

With the exception of Halymenites this species is the most abundant form in the collection, though no absolutely perfect leaf was found. The five leaves selected for illustration give, however, a very complete conception of the whole leaf.

To judge from the figure alone this species would appear to be most closely related to or perhaps even identical with *Rhamnus elegans* Newberry,[1] from Belmont, Colo. This leaf is a little smaller and not quite so abruptly truncate at the base, but in nervation there appears to be very little difference. The type specimen of *Rhamnus elegans*, however, which is preserved in the United States National Museum (No. 10958), presents an entirely different aspect. The nervation is very thin and delicate and the nervilles are made out with much difficulty. Concerning it Newberry says:

> This is a remarkably neat and symmetrical leaf, both as regards its outline and nervation. Its lines are all graceful, with little of the rigidity that characterizes the leaves of most of the Rhamnaceæ and more of the aspect of the leaf of a lauraceous tree, but the numerous parallel side nerves, terminating all in the margins, form a character which the laurels never have.

Notwithstanding the agreement between the leaves in outline, disposition of nervation, etc., it is impossible to believe that the two could belong to the same species. They present a wholly dissimilar appearance when placed side by side.

Some years ago Prof. Junius Henderson, of the University of Colorado, collected a fragmentary leaf from the Fox Hills sandstone at the mouth of Thompson Creek, just west of Evans. This leaf was described by Cockerell[2] under the name Ficus sp. nov., but on account of its fragmentary nature he did not give it a specific name. His description in part is as follows:

> Leaf large, 12 centimeters in diameter, probably about 24 centimeters long, apparently very thick, with pinnate veination, and the margin nearly entire, but faintly undulate, with slightly indicated and remote teeth near the midrib. Lateral veins (secondary) few, alternate, * * * leaving the middle at an angle of about 45°, slightly curved, strongly curved upward toward their ends, where they become parallel with the midrib, finally branching and failing to reach the margin.

Prof. Cockerell has been kind enough to send me a photograph of this specimen, which is here reproduced (Pl. XVII, fig. 4). It shows fragments of three leaves, all evidently of the same species. So far as can be made out, little if any of the actual margin is preserved in either of the leaves, and they do not seem to agree very well with the description. These leaves appear to agree, so far as the characters can be made out, with the specimens collected by Mr. Williard, and they have been so referred.

The propriety of referring these leaves to Rhamnus may perhaps be questioned, and consequently the generic reference has been queried.

[1] Newberry, J. S., The later extinct floras of North America: U. S. Geol. Survey Mon. 35, p. 117, pl. 50, fig. 2, 1898.

[2] Cockerell, T. D. A., A new plant (Ficus) from the Fox Hills Cretaceous: Colorado Univ. Studies, vol. 4, p. 152, 1907.

The species has been named in honor of Mr. Thomas E. Williard, who collected the specimens figured.

Occurrence: Wildcat Mound, 2½ miles south of Milliken, and Thompson Creek, 1¼ miles northeast of Milliken, Colo.; collected by T. E. Williard and T. W. Stanton.

Aristolochia? coloradensis n. sp.

Plate XVIII, figure 3.

Leaf of large size and very thick in texture, broadly ovate in general outline; deeply cordate, perhaps almost perfoliate at the base, obtuse at the apex; margin entire or very slightly undulate; nervation very strongly marked, consisting of a strong, perfectly straight midrib and about nine pairs of secondaries, the three lower pairs opposite and approximately at right angles to the midrib, the others strongly alternate, at an angle of about 45° and curved upward especially above; many of the secondaries, especially in the lower part of the leaf, are forked near or above the middle and produce first a series of very large veins, then a smaller series outside; nervilles very prominent, oblique to the secondaries, mainly broken though occasionally percurrent; finer nervation not preserved. Length about 10 centimeters; width about 11 centimeters.

This large and very strongly marked species is represented only by the specimens figured. It is so curled and wrapped around that it could not be photographed and has been drawn with pen and brush as well as it could be made out. The peculiar branching of the secondaries, especially in the lower part of the blade, is well brought out in the figure. The large loops with the smaller ones outside, as well as the numerous strong nervilles, are also well shown.

There is some uncertainty about the proper generic reference of this large and well-marked leaf, hinging mainly on the interpretation of the basal configuration. If it is merely very deeply heart-shaped it may well enough belong to the genus Aristolochia, being, for instance, not greatly unlike *A. cordifolia* Newberry,[1] especially in the manner of forking of the lower secondaries with the large loops outside. *Aristolochia cordifolia*, as its specific name implies, is deeply cordate at the base and is also markedly unequal-sided.

If, on the other hand, the base is really perfoliate it would suggest certain species of Protophyllum that form a conspicuous element in the flora of the Dakota sandstone. These species, however, are usually very different in general outline and also usually have a more or less incised margin. On the whole, it seems best to place this leaf under the genus Aristolochia with a query. Its characteristic features are so distinct that it can be readily identified if found again and thus must prove a valuable stratigraphic marker.

Occurrence: About 2½ miles south of Milliken, Colo., in sec. 24, T. 4 N., R. 67 W.; collected by T. W. Stanton, July, 1915.

Viburnum vulpinum n. sp.

Plate XVIII, figure 1.

Leaf very firm in texture, nearly circular in outline, slightly heart-shaped at the base, apparently obtuse and rounded at the apex; margin not preserved but presumably dentate; nervation very strongly marked, consisting of a nearly straight midrib and about five pairs of secondaries, the lower pair opposite and the others strongly alternate, the lower ones with several stong tertiary branches on the lower side, and all but the extreme upper ones with some tertiary branches; nervilles very strong, mainly unbroken and at right angles to the secondary or tertiary branches between which they run; finer nervation not retained.

This species is represented only by the example figured, which is nearly perfect except that it lacks the extreme margin. It is nearly circular in shape, being about 9 centimeters long and 8 centimeters wide. It is apparently craspedodrome and presumably ended in marginal teeth of some kind, but this feature can not be ascertained from this specimen.

This species seems undoubtedly to be congeneric with *Viburnum antiquum* (Newberry) Hollick, or *Viburnum tilioides*, as it was called by Ward,[2] a species abundant and widely distributed in the Fort Union formation. The Fox Hills leaf differs from this, however, in having the fewer secondaries at a more acute

[1] Newberry, J. S., The later extinct floras of North America: U. S. Geol. Survey Mon. 35, p. 90, pl. 60, fig. 4, 1898.

[2] Ward, L. F., Synopsis of the flora of the Laramie group: U. S. Geol. Survey Sixth Ann. Rept., p. 556, pl. 61, figs. 1–7; pl. 62, figs. 1–6, 1886; Types of the Laramie flora: U. S. Geol. Survey Bull. 37, p. 107, pl. 50, figs. 1–3; pl. 51, figs. 1–8; pl. 52, figs. 1, 2, 1887.

angle and more curved upward, but the size and general appearance are much the same in both. The margins can not be compared.

Among living species both the present form and the Fort Union species appear to find their closest relationship with the European *Viburnum lantana* Linné and the indigenous American *Viburnum lantanoides* Michaux.

Occurrence: Wildcat Mound, 2½ miles south of Milliken, Colo.; collected by T. E. Williard.

Phyllites cockerelli n. sp.

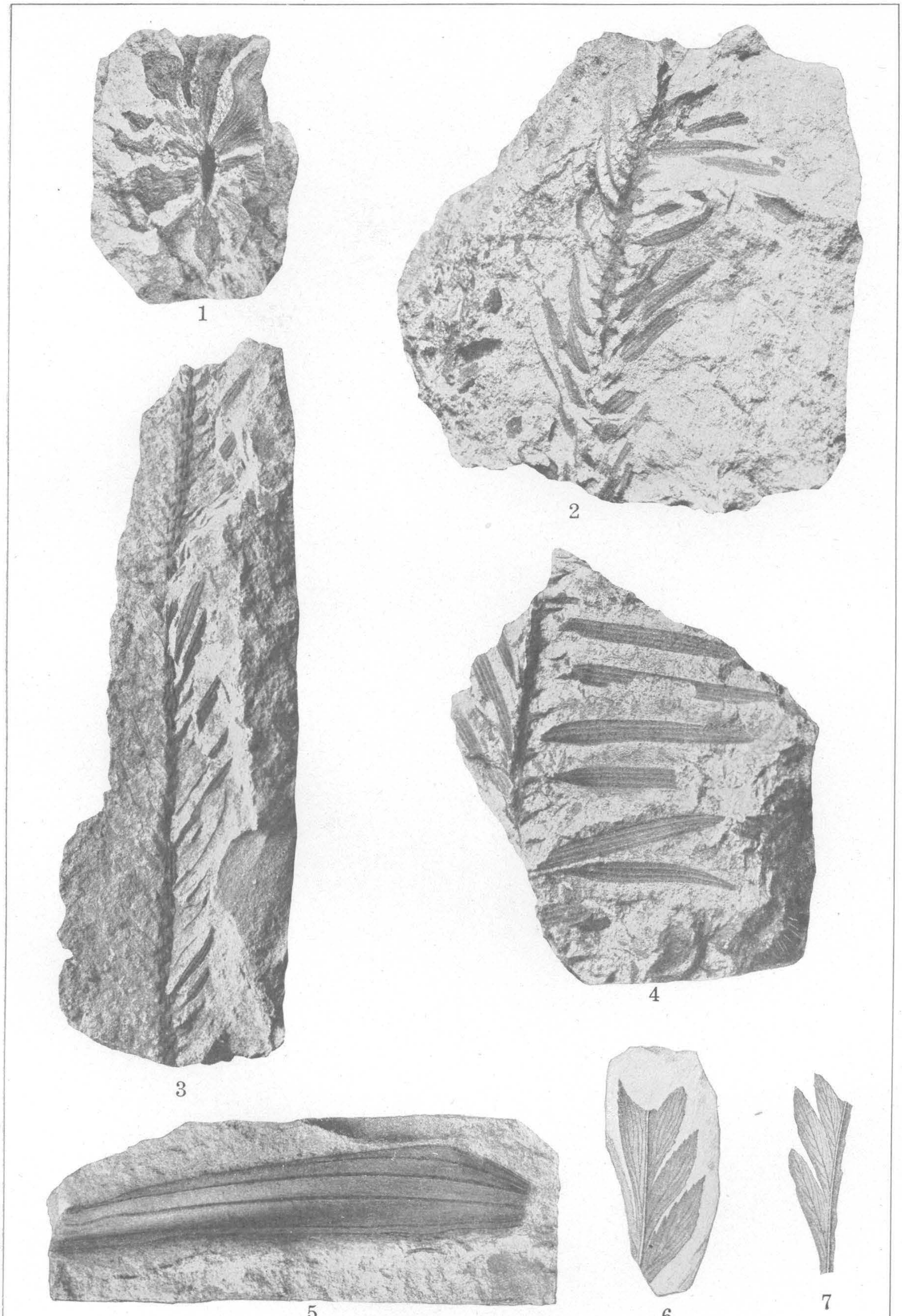
Plate XVII, figures 5, 6.

The collection contains a number of small organisms that on casual inspection were thought to represent the sheaths of Equisetum, but more careful study discloses that they can not possibly belong to that genus. They are funnel-shaped and, so far as can be made out, entire below. Diameter 5 or 6 millimeters below and 15 or 20 millimeters above. They are very strongly ribbed; the ribs are simple or apparently in part forked, and each rib or branch is prolonged into a long, very slender spinelike projection. The number of these spines can not be made out, though apparently there are more than 10.

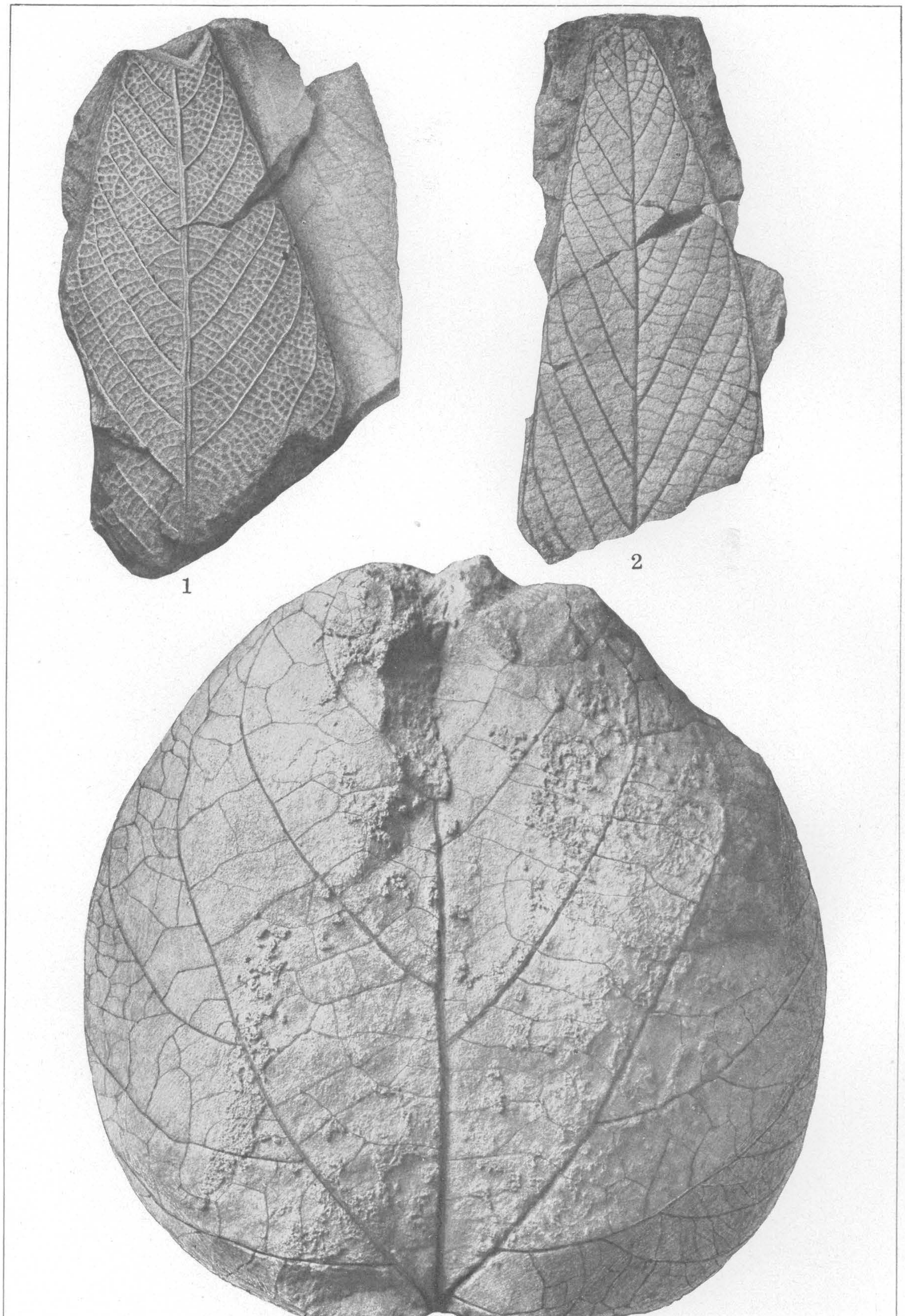
The affinity of these organisms has not been recognized. In some ways they suggest a stipular growth, and they also resemble a persistent, spiny calyx, such, for instance, as in certain Labiateæ and Malvaceæ, but these resemblances are probably purely superficial.

The species is named in honor of Prof. T. D. A. Cockerell, of the University of Colorado.

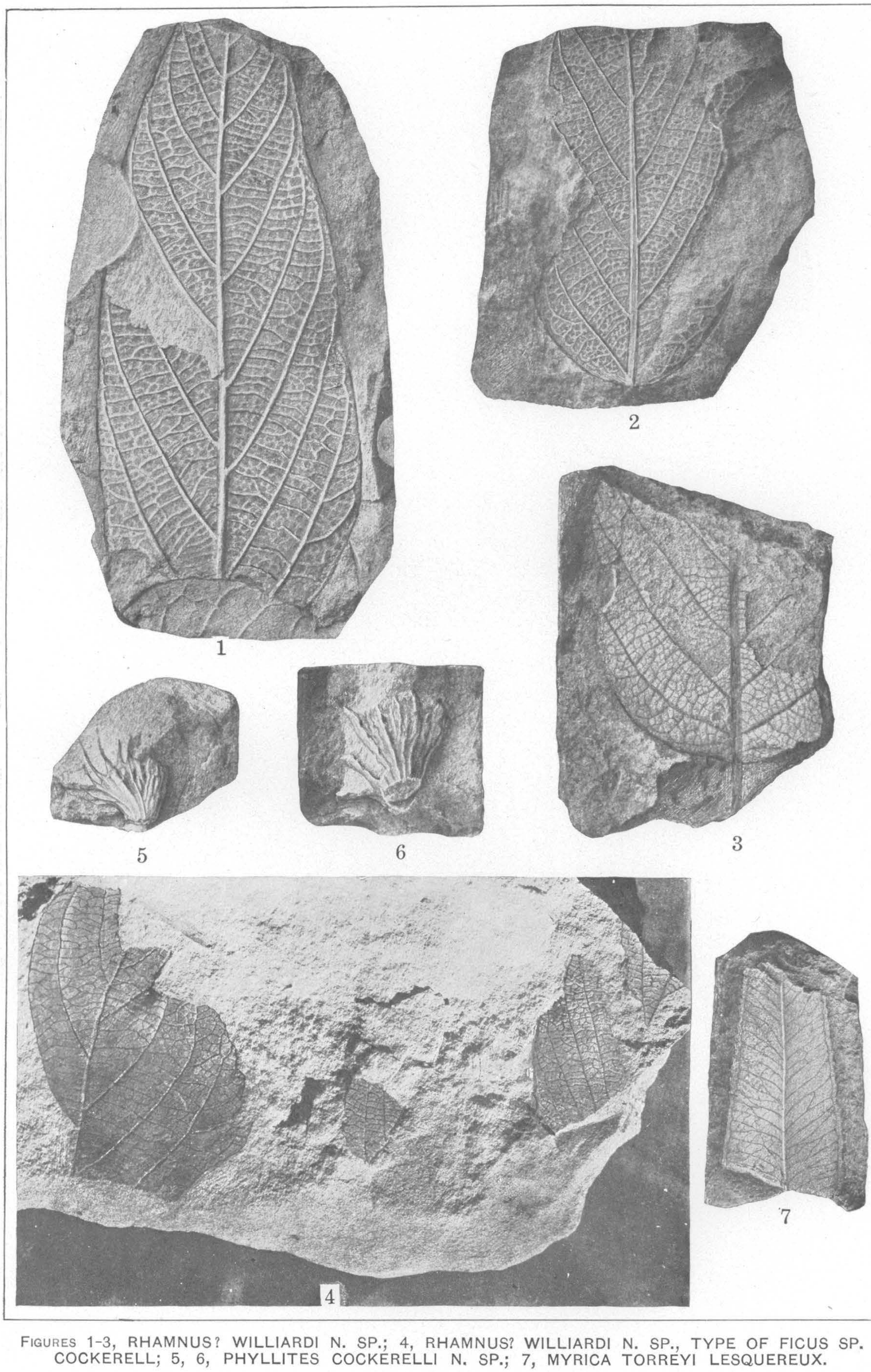
Occurrence: Wildcat Mound, 2½ miles south of Milliken, Colo.; collected by T. E. Williard and T. W. Stanton.



FIGURES 1-3, SEQUOIA MAGNIFOLIA N. SP.; 4, CEPHALOTAXUS? COLORADENSIS N. SP.; 5, PODOCARPUS? STANTONI N. SP.; 6, 7, ANEMIA SP. × 3.



FIGURES 1, 2, RHAMNUS? WILLIARDI N. SP.; 3, FICUS SPECIOSISSIMA WARD.



FIGURES 1-3, RHAMNUS? WILLIARDI N. SP.; 4, RHAMNUS? WILLIARDI N. SP., TYPE OF FICUS SP. COCKERELL; 5, 6, PHYLLITES COCKERELLI N. SP.; 7, MYRICA TORREYI LESQUEREUX.

FIGURE 1, VIBURNUM VULPINUM N. SP.; 2, EQUISETUM SP.; 3, ARISTOLOCHIA? COLORADENSIS N. SP.

A RECONNAISSANCE OF THE ARCHEAN COMPLEX OF THE GRANITE GORGE, GRAND CANYON, ARIZONA.

By L. F. Noble and J. Fred. Hunter.[1]

INTRODUCTION.

The field work upon which this article is based was done in March and April, 1914. From Garnet Canyon, near the west end of the Granite Gorge, the route followed the Tonto trail along the so-called lower plateau, or Tonto platform, to Red Canyon, at the east end of the Granite Gorge. The distance covered was roughly 100 miles measured along the trail, or about 40 miles measured along the course of Colorado River. Supplies were carried by pack burros, and Mr. John Walthenberg acted as packer and guide. Stops of several days each were made at Garnet Canyon, Copper Canyon, Bass Canyon, Serpentine Canyon, Ruby Canyon, Turquoise Canyon, and Slate Creek, in the Shinumo quadrangle; Boucher Creek, Hermit Creek, Salt Creek, Pipe Creek, Lone Tree Canyon, and Grapevine Creek, in the Bright Angel quadrangle; and Cottonwood Creek, Hance Creek, and Red Canyon, in the Vishnu quadrangle.[2]

From Hermit Creek eastward the Tonto trail is often traveled by tourists and was known to be in fairly good shape. The western part of the trail, however, between Hermit Creek and Bass Canyon, was not known to have been used by any party with pack animals since 1905, when the Shinumo quadrangle was topographically surveyed, but progress over it was made with little difficulty. At only one place was it impossible to pass without unloading the pack animals. This was at the head of the small canyon just east of Serpentine Canyon, in the Shinumo quadrangle, where a flood and landslide had carried away the narrow ledges of Bright Angel shale on which the trail passes around the head of the canyon. Except Bass trail and the trail built by Mr. Bass between Bass Canyon and Copper Canyon, there is now very little west of Hermit Creek that can properly be called a trail. The traveler will find the Geological Survey's topographic maps of the greatest value in making this part of the trip, because, although nearly all traces of a trail have disappeared, the route marked on the maps as the Tonto trail still shows the most feasible way along the Tonto platform.

It was thought that there would be difficulty in finding water in many of the side canyons where it was proposed to camp, because most of them do not contain living streams, and the intermittent underground flow derived from the melting snows on the sheltered slopes high under the south rim rarely lasts long after the opening of spring. While the beds of most canyons proved to be dry for the greater parts of their courses, whether on bedrock or on gravelly waste, water was always found flowing for a few hundred yards where the stream courses cross the upper layers of the cliff-making Tapeats sandstone. Most of the camps were made at this level and proved to be equally convenient for the examination of the Archean rocks below the camps and the Paleozoic rocks above, up to the base of the Redwall limestone. During April the small flow of water was constantly diminishing, and it seemed unlikely that there would be any flow whatever by June. It was evident that in any part of the year except early in spring camps at intervals so short and in places so conveniently situated would be impossible.

The chief object of the excursion was the study and areal mapping of the Algonkian and Paleozoic formations of the southern wall of

[1] Field work by Mr. Noble; microscopic study of rocks by Mr. Hunter.

[2] These three quadrangles have been mapped by the United States Geological Survey.

the Grand Canyon in the Kaibab division. Detailed sections of the Tonto group were made in seven places at intervals of 5 or 6 miles, and particular attention was given to the interesting unconformity at the summit of the Tonto group, where the Devonian is present in some places and lacking in others. Three sections of the Carboniferous formations were made, one in each quadrangle. Parts of the three quadrangles were mapped in detail, including all of the Bright Angel quadrangle south of the Granite Gorge, all of the Shinumo quadrangle south of the Granite Gorge as far west as Garnet Canyon, and all of the Vishnu quadrangle south of the Granite Gorge and west of Red Canyon.

are unknown. It was realized that if the Archean could be examined at short intervals through the Granite Gorge it would at least be possible to determine definitely the petrographic character of many of the rocks, and a foundation would be laid for future detailed study. Something might also be learned of their origin and structure. It was therefore decided to make this reconnaissance, and the results are set forth in the present paper. A second paper will be devoted to the detailed discussion of the Paleozoic rocks, and another to a description of the faults in the Grand Canyon on the south side of the river. The location of the known Archean rocks in the Grand Canyon is shown in figure 9.

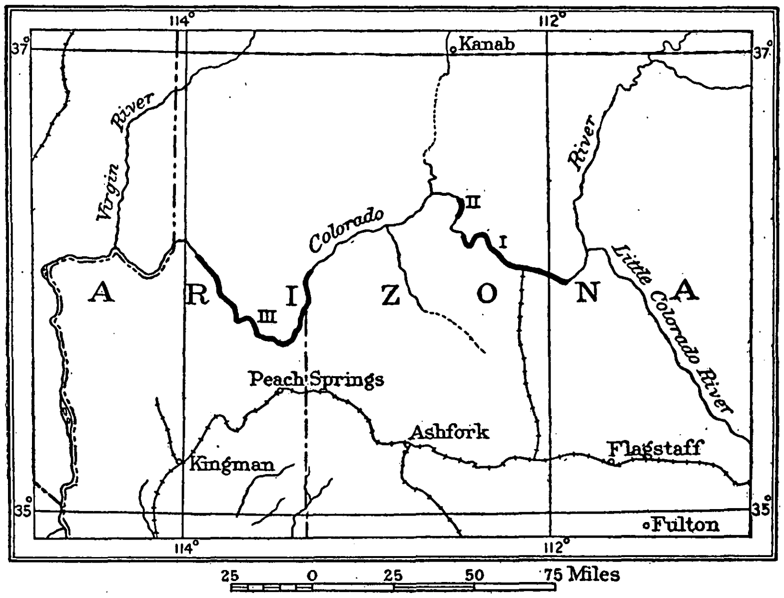


FIGURE 9.—Key map of northwestern Arizona showing location of exposures of Archean rocks in the Grand Canyon. I, Granite Gorge of Kaibab division (described in this paper); II, Lower Granite Gorge; III, Granite Gorge of Shivwits division.

It had not been intended originally to make any examination of the Archean rocks, because an adequate study of their character and structural relations would take at least as much time as the writer had planned to devote to the entire trip. On arrival in the canyon, however, it was found that it would not be difficult to get down to the Archean from camp in each of the larger side canyons and devote a part of the time spent in each camp to the study of these rocks. Geologic literature concerning the Archean complex of the Grand Canyon is very meager, and even the fundamental facts of the lithology and distribution of the rocks

GEOGRAPHY.

Three elements in the topography of the Grand Canyon below the Redwall in the Kaibab division that are important to the geologist who wishes to study the Archean are the Tonto platform, the Tapeats cliff, and the Granite Gorge. All are intimately related to geologic structure.

The Tonto platform, locally misnamed the "lower plateau," is the wide ledge left in the interior of the canyon by the wasting back of the relatively weak Bright Angel shale from the summit of the underlying resistant Tapeats

GRANITE GORGE OF THE GRAND CANYON, ARIZ., LOOKING NORTHWEST.

sandstone.[1] It affords the only possible route of travel through the interior of the canyon on land.

The Tapeats cliff is the outcropping edge of the resistant Tapeats sandstone below the Tonto platform. It is wonderfully persistent, averages 300 feet in height, and is the chief obstacle that bars the way to the Archean rocks.

The Granite Gorge (see Pl. XIX) is the deep, narrow V-shaped canyon which Colorado River has cut in crystalline Archean rocks below the Tapeats sandstone. Descending into it, the traveler leaves the wide outer canyon, whose walls are carved in horizontal Paleozoic strata, and enters what is geologically and scenically another world. At the base of the Tapeats cliff a great unconformity of erosion separates the Paleozoic beds from the two underlying systems of rock—the Archean crystalline rocks and the Algonkian Grand Canyon sediments, which are inset in the Archean in places by block faulting. The change in scenery is no less abrupt than the change in geologic structure. The sides of the Granite Gorge, carved in Archean rocks, descend to the river in steep, bare slopes whose surface is jagged and chaotic in the extreme.

The Granite Gorge is about 40 miles long, measured along the course of Colorado River, and runs from southeast to northwest. The average width between the inclosing cliffs of Tapeats sandstone is perhaps 2,000 feet, and the average depth, measured from the base of the Tapeats cliff to the river, about 800 feet. At irregular intervals of a mile or so tributary gorges are cut back into the Tonto platform. Most of these do not expose the Archean rocks far back from the main gorge of the river, but some of the larger ones expose them for several miles. The upper end of the Granite Gorge begins abruptly in the Vishnu quadrangle near the mouth of Red Canyon, where the river flows southwestward out of great masses of Algonkian strata that dip steeply northeastward upstream. It ends gradually in the Shinumo quadrangle below Garnet Canyon, where the river flows southward across a broad zone in which the Paleozoic strata dip southwestward; as the dip of the strata is greater than the grade of the stream, the river bed is gradually carried out of the Archean rocks into the overlying Tapeats sandstone.

The inaccessibility of the exposures of Archean rocks and the extreme ruggedness of the topography in the Granite Gorge are the chief obstacles to geologic study. The sheer, high cliff of Tapeats sandstone along the rim of the gorge is, in most places, an impassable barrier to descent from the Tonto platform, and there are only three situations in which it has broken down enough to allow the traveler to reach the Archean—(1) at the heads of tributary gorges, where it is cut by stream erosion; (2) in places where a hill or "monadnock" of Archean or Algonkian rock rises through the sandstone and excludes it; (3) where a line of faulting crosses the sandstone and shatters it. The most numerous breaks are those caused by stream erosion at the heads of tributary gorges. Once the Archean rocks are reached progress is exceedingly difficult and slow, except in the beds of the larger tributary canyons, and it is impossible to travel very far along the edge of the river, because the walls rise steeply from the water.

The exposure of Archean rocks in the Granite Gorge is so small a part of the vast areas buried under Paleozoic and later strata north and south of the canyon that the chance of deciphering much of the structure from it would be remote were it not for the fact that the northwest course of Colorado River crosses at right angles the dominant trend of nearly all the structural features in the Archean. Thus the Granite Gorge is a magnificent 800-foot cross section 40 miles in length. The difficulties incidental to the roughness of the topography are largely compensated, for the geologist, by the clearness with which the structure is revealed in the bare slopes.

PLAN OF INVESTIGATION.

The method of study followed was to descend to the Archean rocks in every side canyon where a camp was made and in any other place that could be reached by detour when moving from one camp to another. Twenty localities were visited in traveling the length of the Granite Gorge. The distance between them ranged from three-tenths of a mile to

[1] The Tapeats sandstone is the basal formation of the Tonto group of strata, of Cambrian age, which comprises the Tapeats sandstone, Bright Angel shale, and Muav limestone.

4 miles, but the average interval was about 2 miles. At these localities 67 hand specimens were collected, and thin sections were cut from 48 of them. Eight distinct groups of rocks were crossed in exploring the Granite Gorge, as set forth in the accompanying table. (See also fig. 10.) In this table and the following discussion the localities and groups of rocks are numbered in the order of their occurrence from west to east.

vailing strike of the gneissoid banding is N. 60° E. and the dip nearly vertical. In places between Garnet Canyon and Walthenberg Canyon the strike becomes northwesterly. Here and there the gneiss is greatly mashed and contorted. The commonest type of gneiss is hornblende gneiss (metamorphosed quartz diorite, specimen No. 3), and there are some bands of a very dark hornblende schist (amphibolite, No. 4). A quarter of a mile below the mouth

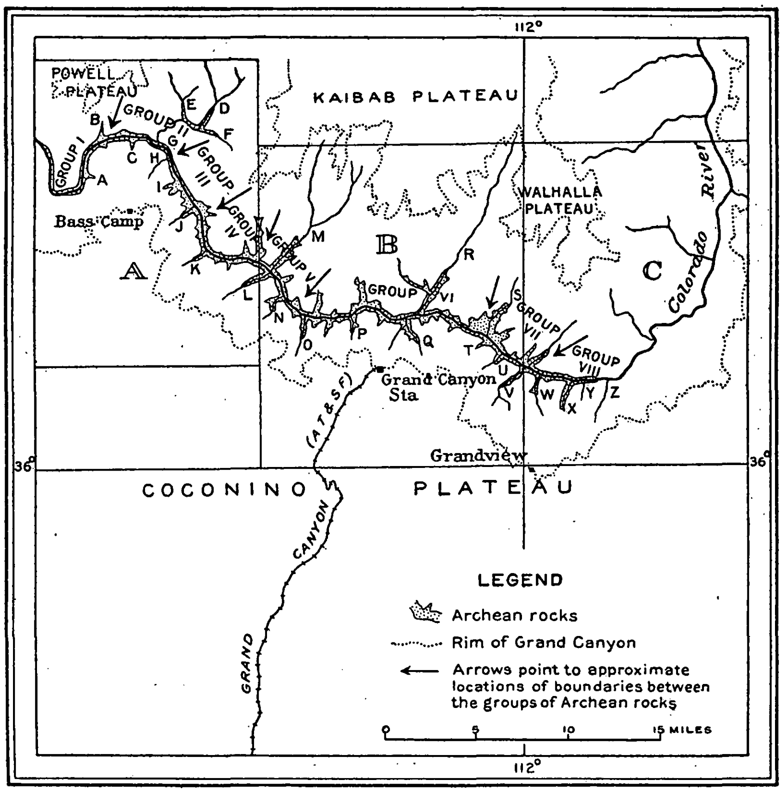


FIGURE 10.—Map of Kaibab division of Grand Canyon, Ariz., showing distribution of Archean rocks and localities where the rocks were examined. Quadrangles mapped by United States Geological Survey are indicated by outline letters as follows: A, Shinumo; B, Bright Angel; C, Vishnu. Localities examined: A, Garnet Canyon; B, Walthenberg Canyon; C, Copper Canyon; D, Shinumo Creek; E, White Creek; F, Flint Creek; G, Cable Crossing; H, Bass Canyon; I, Serpentine Canyon; J, Ruby Canyon; K, Turquoise Canyon; L, Slate Creek; M, Crystal Creek; N, Boucher Creek; O, Hermit Creek; P, Salt Creek; Q, Pipe Creek; R, Bright Angel Creek; S, Clear Creek; T, Lonetree Canyon; U, Boulder Creek; V, Grapevine Creek; W, Cottonwood Creek; X, Hance Creek; Y, Mineral Canyon; Z, Red Canyon.

THE ROCKS.

GROUP I. GNEISSES, AMPHIBOLITES, AND GRANITE.

From the west end of Granite Gorge to the mouth of Walthenberg Canyon, a distance of about 6 miles, the rocks are banded gneisses cut by pink intrusives. The gneisses are of several types and occur in parallel bands which range in width from a few feet to over 300 feet. From Garnet Canyon westward the pre-

of Garnet Canyon there is a 50-foot band of biotite-chlorite gneiss (No. 5) containing numerous garnets about the size of a pea, from which Garnet Canyon was named. Within Garnet Canyon an intrusive body of pink granite (No. 6) is the prevailing rock.

The pink intrusive rocks that are associated with the gneisses are granite, aplite, and pegmatite. The granite is a medium-grained even-textured rock which consists essentially of quartz, microcline, soda plagioclase, muscovite, *Archean rocks examined in Granite Gorge, Grand Canyon, Ariz.*

Quadrangle.	Localities where the Archean rocks were examined and specimens collected (reading from west to east).	Distance between localities (miles).	Nos. of specimens from which thin sections were cut.	Group.	Predominant type of rock.	Approximate length of exposure, measured roughly by the course of the river (miles).[a]
Shinumo.	1. Gorge of Colorado River from mouth of Garnet Canyon to a point 1 mile south	....	3, 4, 5	I	Hornblende gneiss, granite gneiss, and amphibolite (much injected granite and pegmatite).	6
	2. Garnet Canyon (0.2 mile east of mouth)	1.0	6			
	3. Gorge of Colorado River 0.5 mile southwest of mouth of Copper Canyon	2.9	([b])	II	Mica schist (some injected granite and pegmatite).	4.2
	4. Copper Canyon (near mine)	.3	1, 2			
	5. Gorge of Colorado River at Cable Crossing	1.9	8			
	6. Bass Canyon (near mouth)	.4	([c])	III	Massive basic intrusives (some injected pegmatite).	4.5
	7. Serpentine Canyon (head of inner canyon to river)	1.6	9, 10, 11			
	8. Ruby Canyon (0.8 mile southwest of mouth)	1.7	13			
	9. Turquoise Canyon (0.6 mile southwest of mouth)	2.4	15, 16, 17, 18, 20	IV	Metabasite and metadiorite (much injected granite and pegmatite).	2
	10. Slate Creek (1 mile southwest of mouth)	2.9	22, 23, 24, 25, 26, 27	V	Mica schist (little injected granite and pegmatite in eastern part; much in western part).	5.7
Bright Angel.	11. Boucher Creek (0.7 mile southwest of mouth)	1.5	31, 32, 33, 34			
	12. Hermit Creek (head of inner canyon to river)	1.9	35, 38, 39, 40	VI	Granite gneiss and amphibolite (much injected granite and pegmatite).	10.4
	13. Salt Creek (0.7 mile southeast of mouth)	2.7	45, 46			
	14. Pipe Creek (0.8 mile south of mouth)	2.7	49, 50			
	15. Lonetree Canyon (0.5 mile southwest of mouth)	4.0	53, 54	VII	Mica schist (little injected granite and pegmatite in western part; much in eastern part).	3.5
	16. Boulder Creek (0.7 mile southwest of mouth)	1.2	([b])			
	17. Grapevine Creek (1.6 miles southwest of mouth)	1.5	56, 57			
Vishnu.	18. Canyon 0.7 mile southeast of mouth of Cottonwood Creek	2.7	60, 61	VIII	Granite gneiss (much injected granite and pegmatite).	3.7
	19. Hance Creek (1.5 miles southwest of mouth)	1.4	62, 63			
	20. Gorge of Colorado River from mouth of Mineral Canyon to end of Granite Gorge	1.7	64, 65, 66, 67			

[a] Distance in straight line between east and west ends of Granite Gorge, 31 miles; by course of river, 40 miles. [b] No thin sections. [c] See U. S. Geol. Survey Bull. 549, pp. 32-37, 1914.

and biotite, named in the order of decreasing abundance. The aplites and pegmatites consist as a rule of quartz, microcline, and muscovite, but in places the muscovite is absent.

Apparently the pink intrusives comprise from one-fourth to one-third of the rocks of Group I, but the proportion varies considerably from place to place and may be actually much less. Some of them are in sheets parallel with the bands of gneiss. Others, chiefly granites, are in irregular bodies that cut the gneisses. In places the granite in these bodies grades into pegmatite. Still others, chiefly pegmatites, are in dikes that cut both the gneisses and granites.

Petrography of specimens.[1]

No. 3. *Hornblende gneiss* (probably a metamorphosed quartz diorite).—The rock in hand specimen is gray, well banded, and medium grained and contains a considerable amount of quartz in crystals larger than the other mineral constituents. In thin section the gneissoid character is less conspicuous, the rock having a seriate porphyroid fabric in which the individual crystals average about 1 millimeter in the longest direction, although the quartz crystals may be as much as 4 millimeters. Quartz, plagioclase, hornblende, and orthoclase are the essential mineral constituents named in the order of decreasing abundance. The quartz occurs in large irregularly shaped crystals which interlock with and in places include the other constituents. It also contains numerous microscopic inclusions whose character has not been determined. The quartz crystals have no uniformity of orientation, although some of them, particularly those cut at a small angle to the principal optic axis, show undulatory extinction as an evidence of straining. The plagioclase has the composition of andesine (about $Ab_{65}An_{35}$), is usually twinned after the albite law, and is partly altered to sericite. Orthoclase is thought to be present in small amounts but is very much altered. The hornblende crystals are of deep color, showing pleochroism in greens and yellows, and for the most part are arranged with their c′ axes parallel. There is a small amount of leached biotite which is altering to epidote and a reddish mineral thought to be chlorite. The section also contains iron oxides, apatite, zircon, epidote, and titanite in accessory amounts. The rock may have been metamorphosed from a granodiorite or a quartz diorite.

No. 4. *Hornblende schist or amphibolite.*—The specimen is fine grained, black, and schistose. Little else but hornblende can be discerned with the unaided eye. Under the microscope a thin section cut nearly parallel to the schistosity exhibits a seriate fabric in which very few of the individual crystals are as much as 1 millimeter in longer dimension. Mineralogically the rock consists essentially of hornblende, quartz, and feldspar (altering to sericite), named in about the order of decreasing abundance. The feldspar is almost entirely changed to sericite, which is nearly as abundant as the quartz. Epidote and sericite occur in narrow veinlets cutting the other minerals and in small grains associated with hornblende. Titanite is the commonest accessory, but iron oxides, apatite, and zircon, in microscopic size, are also present.

No. 5. *Biotite-chlorite gneiss, or schist.*—This is a dark-green medium-grained micaceous rock, not well lamellated. Its degree of metamorphism is not apparent from the small hand specimen examined. Mineralogically the rock consists essentially of quartz, biotite, chlorite, epidote, sericite, feldspar, and garnet, displaying seriate fabric in thin section in which the grains are as much as 3 millimeters in longer dimension and average about 1 millimeter. The thin section shows little evidence of schistosity or metamorphism of the deeper and regional type. However, the rock has suffered certain profound changes which probably are due more to thermal agencies than to dynamic metamorphism. Thus the feldspars, which apparently were in large part plagioclase, are altered to sericite and chlorite. Some of the chlorite, particularly that which has replaced feldspar, is greenish, but other areas of it are yellow. The yellow variety occurs as pseudomorphs, the original nature of which can not be determined, although the shape of the individuals suggests that they may have resulted from rhombic pyroxene. The epidote occurs in subhedral to euhedral grains and shows noticeable pleochroism in pale yellows to light browns. Fine grains of magnetite and even larger crystals of apatite are abundant. This band may represent a relatively late intrusion into the metamorphic complex.

No. 6. *Granite gneiss.*—Pink medium-grained granite, the small hand specimen of which suggests a more or less gneissoid character. Mineralogically the rock consists chiefly of quartz, microcline, orthoclase, soda plagioclase, muscovite, biotite, and iron oxides, named in order or decreasing abundance. The individual crystals are allotriomorphic, average about 1 millimeter in diameter, and are arranged in a seriate porphyroid fabric as seen in thin section. The rock is relatively fresh, although the feldspars, particularly the orthoclase and soda plagioclase, contain a large amount of finely divided ferritic material, which gives them a dirty reddish-brown appearance in transmitted light. The muscovite is largely secondary, as are also small quantities of sericite, chlorite, epidote, and most of the iron oxides. Apatite occurs as an accessory.

GROUP II. MICA SCHIST.

From the mouth of Walthenberg Canyon to a point about half a mile east of the mouth of Shinumo Creek, a distance of 4⅕ miles, the rocks are rather fine grained dull reddish or

[1] The thin sections were studied microscopically by J. Fred. Hunter in April, 1915. Only the chips from which the thin sections were cut were available for megascopic study.

pinkish mica schists which are cut in places by dikes of pink pegmatite. One of these dikes in Copper Canyon is over 200 feet wide. In general, however, the amount of intrusive rock is small and the schist is free from it over large areas, particularly in the western part of the exposures.

The schist is rather homogeneous in composition. Specimen No. 1, from Copper Canyon, represents the prevailing type of rock. In places where the schist is not too intensely crumpled and mashed, there are numerous alternating bands a few feet in width in which the rock becomes denser, finer grained, and more quartzose in appearance and changes in color from pinkish to gray. In the field the character of this banding strongly suggests an original sedimentary bedding. Specimen No. 2, from Copper Canyon, is the schist from one of these bands of denser rock.

The areas of schist that exhibit this obscure banding are in the western part of the exposures, extending from Copper Canyon to Walthenberg Canyon. Here the prevailing strike of the banding is northwesterly and the dip from 45° to 75° NE., both corresponding in a general way with the strike and dip of the schistosity. If the banding represents an original sedimentary bedding and if there is no duplication by folding or faulting, the exposed thickness of the series can not be less than 5,000 feet and is probably much greater.

East of Copper Canyon, near the contact of the schist with the quartz diorite of Group III, there is a great deal of local twisting and contortion in the schists and they are injected with pink feldspar and milky quartz in veins and lenses. In this area the strike of the schistosity is approximately N. 20° E. and the dip nearly vertical. The schist contains a great deal of pink feldspar and some black tourmaline and in places is rather coarse in texture. Specimen No. 8 is a piece of this schist obtained near the Cable Crossing.

Petrography of specimens.

No. 1. *Mica schist.*—Gray, with pinkish tones; yellow on weathered surface. Mica and quartz individuals are easily distinguishable with the unaided eye. The rock has doubtless been entirely recrystallized during the process of metamorphism, so that no trace of the original structure remains. In a thin section, cut oblique to the cleavage of the rock, the schistosity is indicated by the parallel arrangement of the micas, which average 0.5 millimeter in length, whereas the other constituents average approximately 0.3 millimeter across and a few individuals are as much as 1 millimeter. The mineral composition of the rock may be represented approximately as follows: Quartz $\gg$ biotite $\gtrless$ muscovite $\gtrless$ feldspar $>$ iron oxides, with accessory apatite, zircon, and garnets. The quartz occurs in subequant anhedral grains and is commonly filled with numerous inclusions of mica, apatite, and minute specks whose character has not been determined. The feldspar is likewise anhedral, is altered to sericite and in some places to kaolin, and generally has a lower index than that of quartz. It probably makes less than 15 per cent of the rock. So far as the mineral content is concerned the schist may have been derived from the metamorphism of a shaly arkosic sandstone or equally well from an igneous rock having the general composition of granite.

No. 2. *Mica schist.*—Gray, more compact, and less micaceous than No. 1, but otherwise differing very little, though it is finer grained and the micas are smaller and less conspicuous, giving it a more quartzose appearance. Its mineral constitution is the same, and apparently it has about the same amount of feldspar, which appears to be orthoclase or soda plagioclase.

These rocks resemble pre-Cambrian rocks from the Black Canyon of Gunnison River, in Colorado.[1] The microscopic study does not give conclusive evidence as to their origin.

No. 8. *Muscovite schist.*—Pinkish gray, with silvery sheen in certain light; very micaceous and fissile. The specimen indicates more or less weathering. In a section cut transverse to the cleavage of the rock the parallel arrangement of the micas, which average 0.6 millimeter in length, brings out the schistosity strikingly. The other constituents are allotriomorphic, are equant to subequant, and average 0.2 millimeter in diameter. The mineral composition of the schist may be represented approximately as follows: Quartz $>$ feldspar $\gtrless$ muscovite $\gtrless$ biotite (ferritized) $>$ iron oxides, with accessory apatite, zircon, and garnets.

The feldspar, being badly stained with iron oxide, which gives it a reddish-brown color, is easily distinguishable from the clear quartz and makes up approximately 20 per cent of the rock. It has a low index and appears to have been in part orthoclase, which was somewhat altered to sericite before it was stained by weathering. The biotite likewise is iron-stained and nearly opaque. This rock differs from Nos. 1 and 2 in texture, but is similar in composition, although the degree of weathering has emphasized the abundance of the feldspars.

In addition to the exposures in the Granite Gorge there is an area of the schists in the Shinumo Amphitheater, on the northeast side

[1] A report on the Archean rocks of the Black Canyon region, by J. F. Hunter, is in preparation.

of the West Kaibab fault, 2 miles northeast of the mouth of Shinumo Creek. It extends about 3 miles southeastward in the inner canyons of White, Shinumo, and Flint creeks and a mile northeastward up the canyon of Shinumo Creek. This area of schists was visited in 1908, in the course of a study of the Algonkian strata of the Shinumo quadrangle, and a few specimens of the chief types of rock were collected from which thin sections were made.[1]

Three types of schist were recognized—(1) quartz-mica schists which, in general aspect, resemble the mica schists of the Granite Gorge, above described, and which may contain feldspar, though the two thin sections studied show little or none; (2) fine-grained quartz-hornblende schist, consisting of about equal proportions of quartz and green hornblende; (3) hornblende schist, consisting almost entirely of green hornblende, which occurs in a narrow outcrop with sharp boundaries and apparently represents a body of metamorphosed igneous rock of a basic type.

No definite hypothesis as to the origin of the quartz-mica and quartz-hornblende schists was entertained, because no detailed study was made of the Archean rocks in the field, but the large amount of quartz in the schists suggested a sedimentary origin.

The contact between the gneisses of Group I and the schists of Group II near Walthenberg Canyon was not examined on the present trip, because there was no break in the Tapeats cliff that would permit descent to the Archean within several miles of the contact. Seen from above it appeared to be a rather sharp line crossing the Granite Gorge from northwest to southeast and was thought to be a fault.

GROUP III. MASSIVE BASIC INTRUSIVE ROCKS.

From a point near the Cable Crossing to a point about 1 mile southeast of the mouth of Ruby Canyon, a distance of 4½ miles, the rocks are all coarse granular massive igneous rocks in which no gneissoid banding or schistosity was observed in the localities visited. For at least a mile up the river above the Cable Crossing the rock is a coarse-grained quartz diorite which is intrusive in the schist of Group II. This quartz diorite was examined in 1908 near the mouth of Bass Canyon and has been described as follows:[2]

> The quartz diorite in the river gorge east of Cable Crossing is a coarse-grained, dense, resistant rock of typical granitic texture, which tends to weather into roughly angular blocks and thus to assume forms that distinguish it in the mass from the Vishnu schist. It is dark gray, looks remarkably fresh, and contains visible particles of white striated feldspar, dark hornblende, and glistening black biotite. The rock is uniform in texture throughout the exposures observed, is apparently without contact modifications, and shows no gneissoid banding.
>
> Under the microscope it is seen to be a coarse-granular rock of granitic texture. Its dominant mineral constituents are plagioclase and common hornblende, the plagioclase ranging from oligoclase to labradorite. Microcline, orthoclase, and quartz are present in about equal proportions, but their total amount does not equal that of the plagioclase. Brown biotite appears in somewhat less quantity than the hornblende, and titanite and magnetite are accessories. Occasionally the quartz is poikilitic in the orthoclase. The feldspathic and ferromagnesian minerals occur in about equal proportion. The microscope reveals no cataclastic structure nor other evidence of dynamic action, and the minerals are fresh and unaltered.

In 1908 the rocks of the Granite Gorge were not examined beyond a point 1 mile up the river from the Cable Crossing. It could be seen clearly, however, that they are massive igneous rocks at least as far as the mouth of Ruby Canyon. All the rock in the Granite Gorge between Bass Canyon and Ruby Canyon was therefore mapped as intrusive quartz diorite, but the statement was made in the text of Bulletin 549 that the eastern limit of the diorite had not been located, and the eastern part of the exposure was indicated on the geologic map as outlines by a reconnaissance survey.

On the present trip, when what was supposed to be the quartz diorite was examined in Serpentine Canyon, the next canyon up the river from Bass Canyon where access to the Archean was possible, the rock was found to be a gray porphyritic hypersthene gabbro. Specimens Nos. 9 and 11 came from this locality. No. 10 is a specimen containing one of the phenocrysts. No. 13 is hypersthene gabbro from Ruby Canyon, 2 miles southeast of Serpentine Canyon. The hypersthene gabbro is exposed over an area of about 4 square miles and is the largest single body of massive igneous rock in the

[1] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Ariz.: U. S. Geol. Survey Bull. 549, pp. 32–35, 1914.

[2] Idem, pp. 35, 36.

Granite Gorge. It is characterized throughout by a well-marked sheeting or jointing that strikes northwest and dips 20°–30° NE. It decays more readily than any other rock in the Archean, so the sides of the Granite Gorge in the area occupied by the gabbro have a much gentler slope than elsewhere and the Tapeats cliff has retreated nearly twice as far from the river as it has in the area between Bass Canyon and Serpentine Canyon where the diorite is exposed. The boundary between the diorite and the gabbro must be at the point where this change in the topography takes place and is therefore not far down the river from the mouth of Serpentine Canyon. It was not possible to visit the locality on the present trip, and the nature of the contact is unknown.

Petrography of specimens.

No. 11. *Hypersthene gabbro.*—Gray, with greenish tones when viewed at an angle to the surface, porphyritic with large poikilitic crystals of hornblende. Under the microscope the rock is found to have a poikilitic structure, large crystals of plagioclase and hornblende serving as hosts for hypersthene and augite, which are subhedral to euhedral and 3 millimeters in maximum length. The mineral composition of the rock may be represented approximately as follows: Plagioclase>augite≷hypersthene>hornblende>biotite>iron oxides>chlorite>epidote, apatite, zircon. The plagioclase is extensively altered to sericite, chlorite, and epidote but appears to have been at least as calcic as labradorite. The rock is granular and without schistosity or cataclastic structure and does not seem to have suffered any considerable metamorphism of the regional type.

No. 9. *Hypersthene gabbro.*—Similar to No. 11, but the feldspars are considerably more altered and the section shows hypersthene.

No. 13. *Hypersthene gabbro.*—This rock is very similar to No. 11, is medium grained and porphyritic, and contains large poikilitic phenocrysts of hornblende more than three-fourths of an inch long. Microscopic study shows the rock to be hypidiomorphic and granular and, save for the few large phenocrysts, to have a seriate fabric in which the individual crystals average between 1 and 2 millimeters in diameter, although the plagioclase may be as much as 4 millimeters in length. The composition of the rock may be represented as follows: Plagioclase>hypersthene>hornblende≷augite>actinolite>biotite>chlorite>epidote, with accessory magnetite, pyrite, and apatite. The plagioclase has the composition of labradorite (approximately $Ab_{45}An_{55}$) and is altering to sericite and epidote. The hornblende is changing to a mixture of actinolite and magnetite.

No. 10. *Altered gabbro.*—The hand specimen contains a large phenocryst of hornblende 15 millimeters long and 7 millimeters in diameter. In section the rock is found to consist of large euhedral crystals of hornblende and areas of chlorite aggregates, both of which include anhedral crystals of epidote. The section also contains considerable sericite (after plagioclase), iron oxides, and a small amount of biotite.

Both the diorite and the gabbro are cut by a great mesh of ramifying dikes of pink pegmatite, which is very conspicuous in contrast with the prevailing darker rock and may be distinguished many miles away from points along the rim of the canyon. These dikes, however, though widely distributed, form only a small part of the whole group of rock. In the gabbro many of them have been injected parallel to the sheeted structure. The pegmatite is very coarse and consists of quartz, microcline, and muscovite. In Ruby Canyon the gabbro is altered to a dark hornblende or biotite schist for a few inches away from the contacts of the pegmatite dikes.

GROUP IV. METABASITE AND METADIORITE.

At a point about a mile southeast of the mouth of Ruby Canyon the Granite Gorge narrows abruptly in response to a change in the character of the rock. There is a tremendous increase in the amount of pink intrusive material, and from this point to an undetermined point near the mouth of Turquoise Canyon, a distance of nearly 2 miles, the rocks are chiefly dark-green metabasites and metadiorites, cut by pink intrusives that in some places constitute at least half of the rock. The metabasites and metadiorites are in bands that have a more or less gneissoid structure. Metadiorite, or quartz diorite that has suffered little or no dynamic metamorphism, is the prevailing rock. Specimens Nos. 15, 16, 17, and 18 were obtained in Turquoise Canyon from separate bands, each of which has a width of several hundred feet. The strike is about due east or a little north of east and the dip from 45° to 60° S. Some of the bodies of pink intrusive rock are here more than 200 feet wide, and many of them send off numerous pegmatite veins and stringers into the metabasites. Graphic granite, fine-grained pink granite (No. 20), and coarse pink pegmatite consisting of quartz, microcline, and muscovite are the types present. Crystals of muscovite as much as 4 inches in diameter and crystals of microcline measuring as much as 6 inches were observed in the coarser pegmatite.

Petrography of specimens.

No. 15. *Metabasite.*—Dark-green coarse-grained, rather granular hornblende rock in which poikilitic crystals of hornblende 10 millimeters or more in length predominate over smaller crystals of biotite. In thin section the rock appears to be 80 per cent hornblende, which occurs in large crystals, including biotite, apatite, magnetite, epidote (possibly allanite), and garnet (?), named in the order of decreasing abundance. The constituent minerals are usually very ragged in outline, vary in size, and show no regularity of arrangement. Although the rock exhibits no schistosity or other evidence of dynamic metamorphism it has probably been entirely recrystallized, primarily through thermal agencies. It may have been derived from a basic rock such as gabbro, diabase, or pyroxenite. Rock of this type is not uncommon. In the Lake Superior area it has been called a greenstone, or hornblendite. Other workers have called it amphibolite, and still others metabasite. If a definite name is desired it seems best to use the term metabasite for these nonschistose, thermally metamorphosed rocks, reserving the terms amphibole or hornblende schist and amphibolite for the schistose phase of kindred metamorphic rocks. The term metabasite is applied to metamorphosed basic rocks ranging from metadiorites to amphibolitic schist.[1]

No. 16. *Metadiorite.*—Fine-grained dark-green granular rock. In section the rock has a seriate homeoid fabric in which the individual crystals are allotriomorphic, many of them nearly equant, and average about 0.5 millimeter in diameter. Plagioclase having the composition of calcic andesine is the predominant constituent, and plagioclase and hornblende are the essential minerals of the rock. The feldspar is altering to sericite, and some epidote has been developed. The hornblende crystals have a deep-green color, are of irregular shape, and may not be original. Quartz, if present, is subordinate. The rock also contains apatite, titanite, and iron oxides in accessory quantities. This rock shows no schistosity in thin section or in the small hand specimen. The character of the hornblende suggests that the rock has suffered some metamorphism. It was probably derived from a diorite, although it may have been originally a somewhat potassic gabbro.

No. 17. *Metabasite.*—Dark-green rock similar to No. 15, but finer grained. In thin section hornblende is found to constitute 90 to 95 per cent of the rock. Biotite, iron oxides, apatite, epidote, and possibly quartz are present in subordinate or accessory amounts. The hornblendes are anhedral and of ragged outline, average less than 1 millimeter in diameter, and show no regularity of arrangement. This rock is probably of the same origin as No. 15.

No. 18. *Metadiorite.*—Dark-green hornblende-rich rock resembling No. 16 but of slightly coarser grain. Under the microscope this rock is found to have a seriate fabric in which the individual crystals are anhedral and range from 0.5 to 2 millimeters in longer dimensions. It consists essentially of plagioclase, hornblende, biotite, and iron oxides, named in order of decreasing abundance. The plagioclase is altering to sericite but has the composition of andesine to labradorite. The rock contains a small amount of quartz and an accessory amount of apatite.

No. 20. *Granite.*—Medium-grained even-textured pink granite. In thin section this specimen has a seriate porphyroid fabric in which the individual crystals are anhedral and attain 4 millimeters in longer dimension but average about 1 millimeter. Mineralogically the rock consists essentially of quartz, microcline, soda plagioclase (ranging from oligoclase to albite), muscovite, and biotite named in the order of decreasing abundance. A small amount of orthoclase may also be present, and apatite and iron oxides occur in accessory amounts. Many of the feldspar crystals, particularly plagioclase, have a turbid, reddish appearance due to the presence of very finely divided iron oxides. They are also in small part altered to sericite.

The rocks of Group IV are very similar in character to those of the Gunnison River area in Colorado, as well as to certain pre-Cambrian rocks of the Lake Superior region.[2]

It was not possible to examine the boundary between the rocks of Group IV and the massive gabbro of Group III, but from a distance it had the appearance of an intrusive contact.

GROUP V. MICA SCHIST.

From a point near the mouth of Turquoise Canyon to a point about a mile below the mouth of Hermit Creek, a distance of 5⅝ miles, the rocks are a series of mica, quartz-mica, and chlorite schists in numerous roughly parallel alternating bands which vary in composition and texture and range from a few inches to several hundred feet in width. In a few places there are bands of hornblende gneiss and mica gneiss and a small amount of hornblende schist. All these rocks are very schistose. The prevailing strike is N. 40° E., and the dip ranges from steep northwest through vertical to steep southeast. There is a great deal of local faulting and some crumpling and mashing, so that there are many variations from the prevailing structure, which appears to be, roughly, that of a series of sharply compressed folds. The thickness of the series

[1] It has been used for similar rocks in Finland by G. V. Hackman and J. J. Sederholm.

[2] Williams, G. H., The greenstone schists of the Menominee and Marquette regions of Michigan: U. S. Geol. Survey Bull. 62, p. 146, 1890.

of banded schists can not be estimated, even approximately, but it is probably at least 5,000 feet. All the rocks of this group are cut by dikes of pink pegmatite of the character already described, but east of Agate Canyon the relative amount of this intrusive material is small.

Slate Creek occupies a long, straight canyon which runs about N. 40° E. Across Colorado River and directly in line with the canyon of Slate Creek is the still longer gorge of Crystal Creek, which drains the great Hindu Amphitheater. The rectilinear course of these two canyons is determined by a line of faulting in the Paleozoic strata which has guided their erosion. All the way down the inner gorge of Slate Creek and all the way up the inner gorge of Crystal Creek the strike of the bands of schist is parallel with the course of these gorges, and the dip is vertical or else steep to the northwest or southeast. The same bands of schist that are exposed in Slate Creek apparently continue across the river and on up Crystal Creek to the depths of the Hindu Amphitheater, where a small mass of strata of the Algonkian Unkar group overlies them, so that the total length of the exposure of these schist beds along the strike must be nearly 5 miles. A traverse was made across the upper part of the inner gorge of Slate Creek, in order to ascertain the general succession of the schist series in this locality. Here the structure is fairly simple, the dip being 75° SE. throughout the exposure examined. The section given below reads from west to east:

1. Beds of greenish-gray mica schist (specimens Nos. 22, 24, and 27), alternating with one another and with beds of pinkish-brown quartz-mica schist (No. 23). In some places the separate beds have a thickness of only a few inches; in others they are many feet thick. The contrast between the different types of schist is greater in the field than in thin section, owing to differences in color and in degree of weathering. In the field some of the layers, notably those represented by specimen No. 27, have a well-developed slaty cleavage and might be called slates. The name Slate Creek is derived from the occurrence of this rock. Many of the rocks were supposed in the field to be typical chlorite schists. The quartz-mica schists, owing to their density and fineness of grain, were supposed to be quartzites until the thin sections were examined. In the field there is a vague yet persistent suggestion in these layers of an original sedimentary cross-bedded structure which recrystallization and shearing had not been able entirely to obliterate. This feature and the variation in the schists across the strike suggested that they might be metamorphosed sediments. Thickness, 400 feet or more.
2. Hornblende gneiss (No. 26), apparently representing a metamorphosed quartz diorite that was intruded into the schists. In the field this rock resembles some of the metadiorite of Group IV. Thickness, 300 feet, more or less.
3. Fine-grained, finely banded granite gneiss, occurring, like the hornblende gneiss, in a band parallel with the schist bands. Thickness, 100 feet, more or less.
4. Mica schists of the same character as those of No. 1. Thickness, 200 feet or more.

Although the dominant strike is very persistent, there is a great deal of local folding and crumpling in the schists, and they are injected in places with pink feldspar and milky quartz.

In Boucher Canyon the rocks are essentially the same as on Slate Creek, but the structure is much more complicated by faulting and folding, so that it is difficult to pick out a dominant strike that is characteristic of the area. The dips, as elsewhere in the Archean, are very steep or vertical. The rocks are in alternating bands of varying composition; they are, however, rather more crumpled and mashed than those on Slate Creek. No. 31 is chlorite schist from this locality; No. 32 is quartz-mica schist which is hard to distinguish from quartzite in the field; No. 34 is a very fine grained fissile schist or slate. A bed of hornblende schist (No. 33) occupies a band 200 feet in width between the mica schists.

Petrography of specimens.

No. 22. *Mica schist* (chlorite schist).—Very fissile greenish-gray rock, with pronounced silvery sheen. In the thin section, cut parallel to the schistosity, the rock has a nearly equigranular fabric in which the individual grains range from 0.1 to 0.4 millimeter in diameter and, save for the micas, are equant to subequant. This particular section consisted essentially of quartz, muscovite, biotite, chlorite, altered feldspar, and epidote, named in about the order of decreasing abundance. A section cut transverse to the cleavage would give a better idea of the relative abundance of the mica. Zircon, apatite, garnet, magnetite, and other iron oxides are present in accessory amounts. The feldspars are sericitized, somewhat kaolinized, and stained with ferritic material, so that their character is not determinable. The section studied contains less chlorite than would be suspected from the hand specimen, but this is in part due to the softness of the chlorite and its consequent loss in grinding. These schists may well have been derived from sedimentary rock.

No. 23. *Quartz-mica schist.* — Dense pinkish-brown, very fine textured, banded quartzose rock. In thin section the rock manifests considerable lamellation and is nearly equigranular. The individual crystals average less than 0.1 millimeter in diameter and, save for the micas, are subequant to equant. The section consists of quartz, altered feldspar, muscovite, chlorite, and biotite, named in about the order of decreasing abundance. Curiously enough, the section shows more chlorite than that of specimen No. 22. Like No. 22 the schist contains a rather unusual amount of zircon and considerable magnetite, apatite, epidote, and garnet, all in accessory quantities. The feldspar is more abundant than in No. 22 and is very much altered and stained with iron oxides. Both orthoclase and plagioclase are present. The micas occur in minute individuals, a fact which accounts for the quartzose appearance of the schist in hand specimen.

No. 24. *Mica schist.*—Gray micaceous, very schistose rock with silvery sheen on cleavage surface. In thin section the rock is well lamellated and is made up of allotriomorphic grains mostly 0.3 to 0.5 millimeter in diameter. The essential mineral constituents are quartz, muscovite, and biotite, and the accessory minerals observed are zircon, magnetite, apatite, garnet, and chlorite. The schist contains very little if any feldspar but is richer in mica than No. 23.

No. 25. *Mica gneiss* (or granite gneiss).—Pink, very fine grained, delicately banded gneiss. In section the rock has a pronounced banded structure in which the individual crystals are allotriomorphic and average 0.15 millimeter in diameter. The rock consists of quartz, feldspar (microcline, soda plagioclase, orthoclase?), biotite, and chlorite, named in about the order of decreasing abundance. Epidote, apatite, zircon, magnetite, and other iron oxides occur in accessory amounts. The rock has the composition of a granite and might well be called a granite gneiss.

No. 26. *Hornblende gneiss.*—Dark-green medium-grained hornblendic rock with a strong suggestion of lamellation in the hand specimen. The thin section studied, probably cut parallel to the cleavage of the rock, displays little evidence of lamellation. It shows a seriate fabric in which the individual crystals are allotriomorphic and are 3 millimeters or less in longer dimension. The rock consists essentially of feldspar, quartz, hornblende, chlorite, and biotite, named in order of decreasing abundance. Epidote, zircon, apatite, iron oxides, and garnet are present in accessory amounts. The plagioclase is altered to sericite and is stained with iron oxides but probably has the composition of oligoclase. The hornblende and micas have very irregular and ragged outlines and are entirely without crystal boundaries. The rock represented by this specimen was probably derived from a rock having the composition of a quartz diorite.

No. 27. *Mica schist.*—Very fissile, slaty silver-gray schist. In a thin section cut nearly parallel to the schistosity the rock has a nearly equigranular fabric in which the constituent minerals are subequant to equant and average less than 0.2 millimeter in diameter. The dominant mineral constituents are quartz, muscovite, and biotite. The feldspar has nearly all been altered to sericite but may have constituted as much as 15 or 20 per cent of the rock. Zircon, apatite, epidote, and iron oxides are the commonest accessory minerals. The rock is a mica schist similar in composition to Nos. 22 and 24.

No. 31. *Chlorite schist.*—Silver-gray, micaceous, and very schistose. In a thin section cut nearly parallel to the schistosity the rock has a seriate fabric in which the individual grains are allotriomorphic and range in size up to 0.4 millimeter in length. Quartz, chlorite, biotite, and muscovite are the dominant mineral constituents, and iron oxides, zircon, apatite, tourmaline, epidote, and garnet occur in accessory amounts. Feldspar, in large part altered to sericite, is present in subordinate amount. The chlorite is probably slightly more abundant than either of the micas, so the rock may be called either mica schist or chlorite schist.

No. 32. *Quartz-mica schist.*—Gray compact quartzose schist with inconspicuous micas. In thin section the rock is found to be very fine grained, few of the largest crystals being as much as 0.2 millimeter across and the micas usually being measured in hundredths of a millimeter. It consists essentially of quartz, muscovite, biotite, feldspar, and chlorite, named in about the order of decreasing abundance. The feldspar is subordinate in amount and is in part plagioclase (about oligoclase) in fresh individuals, showing good albite twinning. Epidote, zircon, apatite, calcite, and iron oxides are the commonest accessory minerals.

No. 33. *Hornblende schist.*—Dark-green, moderately schistose hornblende rock. The thin section exhibits a schistose structure in which hornblende crystals making up 90 per cent of the rock, are as a rule from 0.5 to 1 millimeter in length and are entirely without crystal boundaries. Quartz, feldspar, and epidote occur in subordinate amounts; iron oxides, calcite, and apatite are accessory. The feldspar is probably all plagioclase, but is extensively altered to sericite.

No. 34. *Mica schist.*—Very fine fissile, gray schist with thin slaty cleavage. The thin section exhibits fine lamellation, in which the banding ranges from 0.02 to 0.06 millimeter in width, although the individual micas are commonly 0.3 to 0.5 millimeter in length. The principal constituents of the rock are quartz, muscovite, biotite, chlorite, iron oxides, and epidote. Feldspar is present in subordinate amounts, but owing to the fineness of grain and the abundance of dark minerals its relative proportion is difficult to determine.

The mica schists of Group V strongly suggest metamorphosed sediments, but, as is usually the case, microscopic evidence can be considered only auxiliary to the field evidence. The rocks of this group likewise resemble the quartz-mica schists of the Gunnison Canyon area, which have been separated from the more prevalent biotite schist type of that region.

The character of the boundaries between Groups IV and V and between Groups V and VI could not be determined on the present trip.

GROUP VI. GRANITE GNEISS AND AMPHIBOLITE.

From a point about a mile west of the mouth of Hermit Creek to a point about a mile west of the mouth of Clear Creek, a distance of about 9½ miles, the rocks are chiefly granite gneiss and amphibolite.

On Hermit Creek the prevailing rock is a coarse pinkish granite gneiss (No. 35). The gneissoid character is strongly developed, and the banding is very wavy and crumpled in detail. The strike of the gneissoid banding is N. 20° E. and the dip 80° SE. In places the mica in the gneiss is partly segregated in curious porphyritic lumps. No. 40 is a specimen of this phase of the rock. There are areas of a finer-grained gneiss (No. 38), and here and there narrow bands of chlorite schist (No. 39), probably inclusions.

The gneiss is everywhere crowded with pink pegmatitic injections. The pegmatite consists of quartz, microcline, muscovite, and biotite. Some of the bodies of pegmatite are several hundred feet wide and contain crystals of muscovite as much as 6 inches in diameter.

The gneiss in the canyon of Salt Creek (No. 45) is somewhat less micaceous than that on Hermit Creek but differs little in general appearance. It suggests a sheared granite in the field. The strike of the gneissoid banding is N. 20° E. and the dip 75° SE. The gneiss contains some bands of amphibolite (No. 46), which occur at intervals of about 100 feet and range from 1 foot to 6 feet in width. They have the same strike and dip as the gneisses.

The Archean was next visited at the "corkscrew" on the Cameron trail, where the trail descends to Pipe Creek in the line of the Bright Angel fault. The rock west of the fault is a pink medium-grained granite (No. 49) that is somewhat less gneissoid than the gneisses already described but otherwise resembles them in appearance. The rock on the east side of the fault and on the east side of Pipe Creek is a much-contorted greenish hornblende schist (No. 50), which is much injected with pink pegmatitic material. The strike is northeasterly and the dip nearly vertical. This hornblende schist was also found underneath the tiny cap of Unkar strata that lies below the end of the long promontory of Tapeats sandstone jutting out east of Pipe Creek, and it appears to be exposed over a considerable area to the southeast up Colorado River.

Petrography of specimens.

No. 35. *Granite gneiss.*—Coarse, lamellated micaceous rock with large crystals of feldspar and quartz. In thin section the rock exhibits evidence of crushing and partial granulation. The individual crystals have very ragged outlines and are entirely without crystal boundaries. They range in size from a fraction of a millimeter to 3 millimeters. The rock consists chiefly of quartz, biotite, muscovite, sillimanite, and feldspar, with accessory apatite, zircon, garnet, and magnetite. The larger quartz crystals show undulatory extinction. The feldspar is altered and iron stained, but is determinable as orthoclase and soda plagioclase. The sillimanite occurs in myriads of long, slender needles, which give it a fibrous appearance, and is probably of the variety called fibrolite.

No. 38. *Granite gneiss.*—Pinkish-gray, rather fine grained. The gneissoid structure of the rock is well shown in the thin section by the parallel arrangement of the micas. The individual crystals are of irregular outline, and the largest are 1.5 millimeters in longer dimension. Quartz is the most abundant constituent, and with altered feldspar, muscovite, biotite, and chlorite makes up most of the rock. Garnet, iron oxides, apatite, and zircon are the commonest accessory minerals. The feldspar is sericitized and stained with iron oxides, but is in part determinable as soda plagioclase. The gneiss was probably derived from a granite and may be called either a granite gneiss or mica gneiss.

No. 39. *Chlorite schist.* — Greenish-gray schistose rock. In thin section the schistosity of the rock is very pronounced. The bands of chlorite alternate with quartz and sericitic muscovite, which has apparently been derived from the alteration of feldspar. The rock is rather fine grained, the quartz crystals and pseudomorphs after feldspar being, as a rule, not more than 0.3 millimeter in longer dimension, although the chlorite crystals may be as much as 3 millimeters in length. Quartz, chlorite, and sericitic muscovite are the chief mineral constituents; subordinate amounts of feldspar and iron oxides, with accessory apatite, zircon, garnet, and epidote, are also present.

No. 40. *Segregation in gneiss.*—The chip is largely muscovite in a well-lamellated, contorted structure, with feldspar and quartz. The microscope reveals a mixture of quartz, altered feldspar, muscovite, chlorite, and iron oxides. Some of the muscovite crystals are very large and poikilitically include the other constituents. The feldspar is altered to sericite, somewhat kaolinized and iron stained, but apparently was originally orthoclase and soda plagioclase. Zircon and apatite were observed in accessory amounts. The mineral constituents of the rock are entirely without crystal boundaries, and many of the mica crystals are contorted and broken.

No. 45. *Granite gneiss.*—Pinkish gray and well banded. The thin section exhibits gneissoid structure with a seriate fabric in which the individual crystals are allotriomorphic and range from a fraction of a millimeter to 5 millimeters in longer dimension. Quartz, feldspar, and mica are the dominant minerals; iron oxides, apatite, and zircon occur in accessory amounts. The feldspar consists of microcline, soda plagioclase, and orthoclase and is slightly altered to kaolin and, in a less degree, to sericite.

No. 46. *Hornblende schist or amphibolite.*—Dark green, medium grained, and very schistose. In a section cut nearly parallel to the cleavage the schistosity, which is well displayed in the hand specimen, is not at all evident. Hornblende, soda plagioclase, and quartz are the principal constituents; apatite, iron oxides, and zircon are present in accessory amounts. The plagioclase is largely altered to sericite but apparently had the composition of oligoclase to andesine. This schist is similar to No. 4, of Group I.

No. 49. *Granite.*—Pink medium-grained biotite granite. In thin section the rock has a seriate porphyroid fabric in which the individual crystals are allotriomorphic and range in size from a fraction of a millimeter to more than 2 millimeters. Quartz, feldspar, and biotite are the principal constituents; iron oxides, zircon, and apatite occur in accessory quantities. The feldspar is somewhat kaolinized and consists of microcline and plagioclase having the approximate composition of oligoclase.

No. 50. *Hornblende schist.*—Dark-green medium-grained schistose rock, with reddish feldspar. In section the rock shows a schistose structure produced by the parallel arrangement of the hornblende crystals. The individual minerals are allotriomorphic and range from a fraction of a millimeter to more than 2 millimeters in longer dimension. The rock consists essentially of hornblende, plagioclase, quartz, and biotite, named in about the order of decreasing abundance. The plagioclase, which has approximately the composition of andesine, has a reddish color due to inclusions of numerous minute specks of iron oxide. Apatite, titanite, epidote, iron oxides, and calcite were observed in accessory amounts.

About a mile west of the mouth of Clear Creek, on the north side of the river, there is a huge irregular body of what appears to be massive granite in the gneisses. Owing probably to its massive character this rock resisted the pre-Cambrian erosion and now projects well above the plane of the unconformity at the base of the Tapeats sandstone and excludes the sandstone entirely. This monadnock was noted by Davis.[1] It is, so far as known, the highest monadnock of Archean rock in the Kaibab division of the canyon, although it is several hundred feet lower than a number of the monadnocks of Algonkian quartzite.

GROUP VII. MICA SCHIST.

From a point half a mile west of the mouth of Clear Creek to a point near the mouth of Grapevine Creek, a distance of 3½ miles, the rocks are a series of mica schists and mica quartzites which strike northeast and dip vertically or steep northwest. These rocks, exposed southwest of Vishnu Temple, were named the Vishnu terrane by Walcott,[2] who recognized their sedimentary origin. In the exposure across the strike there is probably some duplication by folding or faulting, but the thickness must be at least 5,000 feet. The same rocks are exposed for a distance of 2 miles along their strike in the gorge of Clear Creek, on the north side of Colorado River.

In Lone Tree Canyon the prevailing rock is a fine-grained pinkish to greenish gray quartz-sericite schist (No. 53), which is the least metamorphosed rock of supposed sedimentary origin that was found in the Archean complex in the Grand Canyon. The original bedding can be made out in places and corresponds in the main with the direction of the schistose banding; the separate beds are distinguished by slight differences in color and texture. Nearly all the rocks have a very fine, almost paper-thin slaty lamination. Some beds display a faint cross-bedded structure. The prevailing strike is between N. 20° E. and N. 70° E., and the dip between 45° and 80° NW. They are cut by numerous faults of small throw. It seemed probable in the field that the rock was originally a micaceous shaly sandstone like the Dox sandstone of the Algonkian Unkar group or like many beds in the Cambrian Tonto group. Curiously, many of the beds show numerous small circular spots of a magenta color which are similar to the spots found all through the strata of the Unkar and Tonto groups.

Specimen No. 54 is a piece of sandstone from the overlying unmetamorphosed Tonto group taken for comparison with the Archean specimen No. 53. When the labels are removed it

[1] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Harvard Coll. Mus. Comp. Zoology Bull. 38, geol. ser., vol. 5, No. 4, fig. 15, p. 174, 1901.

[2] Walcott, C. D., Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado, Ariz.: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 506, 1894.

is impossible to tell with the unaided eye which is the unmetamorphosed rock, and in thin sections the resemblance is almost as close.

The rocks of Lone Tree Canyon greatly resemble in the field those of Group V in Slate Creek, in the Shinumo quadrangle, but are less metamorphosed. There are no pink intrusions in the schists of Lone Tree Canyon, but there is a small amount of milky quartz in thin veins and stringers.

In the canyon of Boulder Creek the rocks and structure are practically the same as in Lone Tree Canyon.

In the canyon of Grapevine Creek, near the east end of the exposures of Group VII, the rocks are mica schists and quartz-mica schists in alternating bands, injected by dikes of coarse pink pegmatite. There is a great deal of milky quartz in the schists, in veins and stringers. The pink intrusive rocks are of the same character as those in other groups of the Archean. In this locality they occur for the most part in very irregular masses, some of which appear to be mashed and folded with the schists. Specimen No. 56 is mica schist from the canyon of Grapevine Creek; No. 57 is quartz-mica schist. There is a great deal more evidence of metamorphism here than in Lone Tree Canyon. The schists are greatly mashed and contorted and no prevailing strikes and dips are obtainable. These rocks in the canyon of Grapevine Creek resemble in the field those near the eastern boundary of Group II, at the Cable Crossing, in the Shinumo quadrangle.

Petrography of specimens.

No. 53. *Quartz-sericite schist.*—White, with pink tones on cleavage surface. Thin-bedded, platy, with fine sandy texture on surface transverse to cleavage. In thin section quartz is the most abundant mineral and occurs in allotriomorphic grains usually less than 0.2 millimeter in diameter, although there are coarser segregations in which the crystals may be as much as 0.5 millimeter across. These coarser areas show less interstitial material and may represent pebbles in the original sediment. The quartz grains are cemented together by a finely comminuted aggregate composed chiefly of sericitic muscovite, chlorite, and epidote, which may have been derived from the cementing material of the original rock. Considerable feldspar may have originally been present, but it is now almost entirely altered to sericite and in minor degree to kaolin. Muscovite, biotite, and epidote occur in subordinate amounts; zircon, tourmaline, apatite, and iron oxides are the commonest accessory minerals. The rock has the appearance of a more or less metamorphosed shaly sandstone or grit, although it does not show pronounced evidence of recrystallization and pressure. The term quartz-sericite schist is suggested as indicating its content and structure without connoting its origin. The terms mica quartzite or sericite quartzite might be used equally well. The rock is strikingly similar in structure and composition to specimen No. 54, from the Cambrian Tapeats sandstone, although it is less even grained and apparently contains more interstitial material. However, a section oblique to the cleavage would have been more satisfactory for comparison of the two rocks than the one studied.

No. 54. *Tapeats sandstone.*—Bluish-gray thin, platy sandstone. The section, cut obliquely to the cleavage of this rock, resembles No. 53 rather closely. More than 90 per cent of the rock is quartz in grains of irregular shape, averaging about 0.2 millimeter in diameter. Mica, chiefly biotite, and sericitic muscovite have been developed and occur in bands about 0.5 millimeter apart, giving the rock its good cleavage. A few relics of much-altered feldspar are present, and chlorite, epidote, zircon, and iron oxides were observed in subordinate or accessory quantities.

No. 56. *Mica schist.*—Gray, with silvery sheen on cleavage surface, well lamellated and fine grained. In section the rock has a pronounced schistose structure in which the individual grains are allotriomorphic and are usually less than 0.2 millimeter in diameter, although the micas may be as much as 1 millimeter in longer dimension. Quartz, muscovite, and biotite are the chief mineral constituents of the rock. The feldspar has been almost entirely altered to sericite and kaolin but was probably subordinate to the minerals named. Epidote, zircon, apatite, and iron oxides were observed in accessory amounts.

No. 57. *Quartz-mica schist.*—Fine grained, compact, dark gray, quartzose. In thin section the rock has a vague schistose structure, and the individual crystals are allotriomorphic and average about 0.2 millimeter in diameter. Quartz, feldspar, biotite, and muscovite are the dominant mineral constituents, named in about the order of descending abundance. The feldspar is altering to sericite and in less degree to kaolin but apparently was originally orthoclase and soda plagioclase. The micas are not so abundant as in most of the other schists and occur in fine leaves. Zircon, apatite, epidote, and iron oxides are the commonest accessory minerals.

Specimens Nos. 56 and 57 resemble Nos. 31 and 32, respectively.

As was the case with most of the other groups of Archean rock, neither the eastern nor the western boundary of Group VII could be reached on the present trip because there was no place near them where a break in the Tapeats cliff would permit descent. Viewed from a distance, the boundary between Groups VI and VII appeared to be a fault, but the increasing intensity of metamorphism and the injected character of the eastern border of

Group VII suggested that the boundary between it and Group VIII may be an intrusive contact.

GROUP VIII. GRANITE GNEISS.

Group VIII is exposed from a point near the mouth of Grapevine Creek to the east end of the Granite Gorge, a distance of $3\frac{7}{10}$ miles. The rocks were examined in the small canyon half a mile east of Cottonwood Creek, in the canyon of Hance Creek, and in the Granite Gorge between Mineral Canyon and Red Canyon. In the locality east of Cottonwood Creek the prevailing rock is a much-contorted pinkish gneiss (No. 60), which in places grades into a more micaceous gneiss (No. 61). The gneiss is much injected by pink pegmatite and milky quartz, which appear to be folded with it, and is cut by younger bodies of pink pegmatite. Because of the intense crumpling of the gneiss there is no general strike and dip traceable over any large area.

The gneiss in the canyon of Hance Creek resembles that just described. There are two chief types which grade into each other—a pink granite gneiss (No. 62) and a gray micaceous gneiss (No. 63). The amount of pink pegmatitic material is even greater than in the locality east of Cottonwood Creek, and some of it may be folded and mashed with the gneiss. In places the gneiss itself grades into pegmatite and aplite. The contortion is so great that no prevailing strike and dip can be made out.

Between Mineral Canyon and the east end of the Granite Gorge the rocks are in gneissoid bands of varying composition, but the prevailing rock is pink granite gneiss (Nos. 64 and 66). There are scattered bands of garnetiferous mica schist (No. 65) and bands of biotite schist (No. 67), also considerable pegmatite. In general, the strike of the gneissoid banding is northeasterly and the dip nearly vertical.

Petrography of specimens.

No. 60. *Granite gneiss.*—Red, fine-grained, and banded. The section, which is cut parallel to the banding, exhibits a seriate porphyroid fabric in which the individual crystals range from a small fraction of a millimeter to more than 1 millimeter in diameter. Quartz, feldspar, and biotite are the principal constituents. The feldspar consists of orthoclase, microcline, and microperthite, in nearly equal amounts, and plagioclase having about the composition of oligoclase. The plagioclase and orthoclase particularly and the microcline to a less degree are weathered and stained and include numerous fine grains of iron oxides which give them a reddish color. The biotite is leached out and is altering to chlorite. Muscovite, apatite, zircon, and iron oxides occur in subordinate or accessory amounts.

No. 61. *Mica gneiss.*—Well-banded gneissoid rock containing considerable mica. Under the microscope the rock exhibits a gneissoid structure and is made up of allotriomorphic crystals, the majority of which range between 0.5 and 1.5 millimeters in longer dimension. Quartz, plagioclase (chiefly oligoclase), biotite, and orthoclase are present, named in about the order of decreasing abundance. As in No. 60, the feldspars are weathered and iron stained and the biotite is being leached and altered to chlorite. Zircon, apatite, and magnetite are present as accessory minerals; chlorite, iron oxides, and epidote are largely products of surface alteration. The composition of this rock hardly permits its being considered a metamorphosed granite of the normal microcline type. The uneven fracture, the segregation of the several constituents, and the general appearance in the hand specimen, together with the predominance of plagioclase over potash feldspar in the thin section suggest that it is an injection gneiss.

No. 62. *Granite gneiss* (or gneissoid granite).—Pink medium-grained granitic rock. The thin section exhibits a seriate intersertal fabric in which the individual crystals are allotriomorphic and range in diameter from less than 0.5 to 2 millimeters. The rock consists of quartz, microcline, soda plagioclase, orthoclase, biotite, and muscovite, named in approximately the order of decreasing abundance. The orthoclase and plagioclase are extensively altered to sericite and kaolin and are colored red by fine inclusions of iron oxides. Apatite, zircon, and magnetite occur in accessory amounts, and muscovite, epidote, chlorite, and iron oxides are for the most part products of alteration. Many of the larger individuals, particularly the microcline, show poikilitic structure in thin section, and a few of the quartz grains show undulatory extinction. This feature, together with the intersertal fabric, is indicative of the mashing and partial recrystallization suffered by the original granite.

No. 63. *Granite gneiss.*—Dark-gray medium-grained biotite-rich gneiss. In thin section the gneiss has a seriate fabric in which the individual crystals are of irregular shape and range from a fraction of a millimeter to more than 3 millimeters in longer dimension. Quartz, altered feldspar, biotite, and muscovite are the principal constituents. The feldspars are extensively weathered and iron stained, and kaolin is the chief alteration product, although considerable sericite has also been developed. Some of the biotite is brown and some green, and it is in many places leached or altered to chlorite and magnetite. Epidote, zircon, apatite, and iron oxides occur in minute quantities.

No. 64. *Granite gneiss.*—Pinkish fine-grained granite gneiss. In section the rock has but a suggestion of gneissoid structure and has a seriate intersertal fabric in which the individual crystals are allotriomorphic and are as a rule not more than 1 millimeter in longer dimension. Mineralogically the rock is very similar to Nos. 60 and 62 and consists essentially of quartz, soda plagioclase, microcline, muscovite, biotite, and possibly a small amount of orthoclase, with the usual accessory and secondary constituents. The undulatory extinction of the quartz, the poikilitic character of the larger crystals of microcline, and the intersertal fabric are evidences of the pressure and partial recrystallization suffered by the rock.

No. 65. *Coarse garnetiferous mica schist.*—Coarse, well-lamellated mica aggregates. The section shows a schistose mixture of biotite, muscovite, garnets, and iron oxides (chiefly magnetite). The micas are 10 millimeters or more in length. The garnets are pink, many of them include biotite and iron oxides, and a few are surrounded by rims of chlorite, to which the garnet is apparently altering. A few grains of zircon were observed, and a small amount of badly stained feldspar may be present in one of the two slides studied. No quartz was recognized in the sections, although a little may be present in the hand specimen.

No. 66. *Granite gneiss.*—Pinkish gray and gneissoid. Under the microscope the rock is found to have a seriate intersertal fabric in which the individual crystals are allotriomorphic and range in size from a small fraction of a millimeter for the interstitial crystals to 4 millimeters and more for the larger ones. The rock is very similar to the granite gneisses already described and consists of quartz, orthoclase, microcline, soda plagioclase, biotite, muscovite, and iron oxides, named in about the order of decreasing abundance. Apatite and magnetite occur in accessory amounts, and chlorite, sericite, kaolin, epidote, and iron oxides have resulted from weathering and other processes of alteration.

No. 67. *Biotite schist.*—Dark gray, with obscure pinkish tones; well foliated and reddish brown on weathered surfaces. A section cut parallel to the schistosity discloses a nearly equigranular fabric in which the individual crystals are allotriomorphic and, save for micas, are rarely as much as 0.2 millimeter in diameter. The micas are of irregular and ragged outline and are usually about 0.3 millimeter in longer dimension. Feldspar, extensively altered to sericite, quartz, and biotite, are the principal mineral constituents, and apatite, iron oxides, epidote, zircon, and garnet were observed in accessory amounts. The feldspar is too much altered for determination but was originally present in quantity equaling or exceeding the quartz. Inclusions of apatite prisms are unusually numerous, but muscovite of the sericitic variety is rare or absent. This rock has been entirely recrystallized and has been rendered completely schistose during the process of metamorphism, so that no trace of its original structure remains. However, it was most probably derived from a massive igneous rock of granitic character. It resembles Nos. 1, 3, and 4 and other mica schists already described, although under the microscope it is found to have a higher feldspar content. It is very similar to the most prevalent type of biotite schist of the Gunnison River area in Colorado.

CONCLUSIONS.

CORRELATION.

It will be apparent to the reader that the present study, which was made at points where the topography permitted access to the Archean rather than in places where the importance of Archean structure demanded attention, has yielded data that are rather too fragmentary to be of much value in solving the problems of Archean structure and history in the Grand Canyon region. Yet it has afforded a fair estimate of the general character of the rocks, and a few conclusions may be drawn.

The three groups of mica schist (Groups II, V, and VII) are apparently parts of a single series of rocks. They are practically identical in mineral composition, are similar in appearance in the field, and are supposed to have had, for the most part, a similar origin.

Groups I, VI, and VIII, chiefly granitic gneiss, hornblende gneiss, and amphibolite, comprise rocks which, collectively, are very similar in lithology and structure. They may be included in one series and called gneisses, although the rocks within the groups represent several periods of geologic time and doubtless when a detailed study is made they will be differentiated into more than one series on the evidence of their origin and history.

The relations of the greenstones comprising Group IV are uncertain, but the metabasites resemble many of those in the gneiss series. It seems probable that this group belongs with the gneisses, though further investigation may show that the metadiorite is a part of the diorite of Group III that has suffered thermal metamorphism.

The massive basic rocks are the quartz diorite and hypersthene gabbro of Group III. They probably represent postdeformation intrusions or, at any rate, relatively late intrusions in the complex.

The pink siliceous intrusive rocks comprise granite, aplite, and pegmatite and are the most widely distributed of the Archean rocks. They probably represent several periods of igneous activity. The older material is associated chiefly with the gneisses and in places appears to be mashed and folded with them. It does not appear to be associated with the schists except in places near the borders of the schist groups. The younger material is by far the most abundant and widely distributed rock of the series. It is chiefly coarse pegmatite, which occurs typically in dikes that cut every group of rock in the Archean.

Estimated roughly, the gneisses comprise perhaps 50 per cent of the rocks exposed in the Granite Gorge, the mica schists 30 per cent, the basic intrusive rocks 10 per cent, and the pink siliceous intrusive rocks 10 per cent. The relative amount of the pink siliceous rocks is hardest to estimate because of their wide though irregular distribution. It may be very much more than 10 per cent.

ORIGIN AND HISTORY.

The mica schists are clearly the products of regional metamorphism, for nearly everywhere they are thoroughly schistose and entirely recrystallized. Those in Lone Tree Canyon are the least metamorphosed, and in that locality there is evidence that they represent an originally sedimentary series. Inasmuch as the mica schists in all the other localities are very similar in mineral character to those in Lone Tree Canyon, it seems not improbable that they also are in large part, if not entirely, of sedimentary origin.

Both the field relations and the microscopic study indicate that the gneisses are igneous in origin, but it is clear that they have had a long and complex history. Most of them are medium to coarse grained rocks with a pronounced gneissoid structure, which is in general parallel in trend with the similar structure in the schists. These gneisses, with the schists, have gone through at least one period of regional metamorphism. Many of the gneisses are thoroughly recrystallized; some appear to represent metamorphosed quartz diorites; others, metamorphosed granites; still others, metamorphosed basic rocks. Some of the granite gneisses are injection gneisses; others, very little altered, are pressed granites. Throughout the gneisses granitic rock,[1] whether older and very gneissoid or younger and little sheared, is the predominating type. In places the gneiss contains bodies of chlorite or mica schist that are thought to be inclusions.

Perhaps the most important problem of the Archean geology of the region is the relation of the gneisses to the schists. If the schists are, as the evidence seems to indicate, a metamorphosed sedimentary series, are the gneisses the basement upon which these old sediments were laid down, or are the gneisses wholly or in part intrusive in the schists? The solution of this problem must depend on future study in the field. Unfortunately, on the present trip, none of the boundaries between the groups of rocks were near the places where access to the Archean was to be had, and so they could not be examined. These boundaries are the critical localities of the Archean, and the study of them will undoubtedly lead to the deciphering of much of the geologic history.

Some evidence that may aid in solving this problem was obtained on the present trip. On Slate Creek a broad band of hornblende gneiss was found between the prevailing bands of mica schist; associated with the hornblende gneiss is a band of mica gneiss or granite gneiss. The study of these gneisses in thin section indicates that the hornblende gneiss is a metamorphosed quartz diorite and that the mica gneiss is a metamorphosed granite. The hornblende gneiss and the mica gneiss appear to represent quartz diorite and granite intruded into the schists before the close of the period of regional metamorphism. Thus it is probable that a part, at least, of the rocks of the gneiss series are intrusive in the schists.

The great amount of pegmatitic material in the schists near the eastern boundary of Group VII suggests that this boundary may prove to be an intrusive contact between the schists and the granitic gneiss (probably an injection gneiss) of Group VIII.

It is the impression of the writers that when the history of the gneisses and schists is worked out it may be found that some of the greatly wrinkled and contorted granitic gneisses are the oldest rocks of the Archean and are a part of the original basement upon which the schist series of metamorphosed sediments was laid down; that both before and for some time after the deposition of the sediments there were long periods of complex igneous intrusion now represented by amphibolite, granite gneiss, and metadiorite; and that some of these intrusives penetrated the sediments after they were deposited.

The most obvious event in the Archean history is the regional metamorphism that in-

[1] The term granitic is used here in a broad sense for rocks that were originally granite, granodiorite, monzonite, or quartz diorite.

volved both the gneiss and schist series. As a result of it most of the rocks were recrystallized and nearly all of them acquired a gneissoid or schistose banding which has a dominant northeast strike and a nearly vertical dip. This structure suggests that the compressive forces acted either from the northwest or from the southeast. It may be noted that a similar structure characterizes the Archean complex in the Globe region described by Ransome,[1] and the complex on the west and southwest border of the Grand Canyon district, described by Schrader.[2]

The massive basic intrusive rocks of Group III may be younger than the period of regional metamorphism. The quartz diorite cuts the schists of Group II, but the relation of the gabbro to the diorite and that of both the gabbro and the diorite of Group III to the rocks of Group IV are not known. None of the earlier pink siliceous intrusives are found in the diorite and gabbro, which, however, are cut by the later pegmatites of the pink siliceous series.

The age of the earlier granite and pegmatite of the series of pink siliceous intrusives is not clear. Some of the material is associated with certain granite gneisses in such a way as to suggest that its intrusion accompanied or closely followed that of the material from which this gneiss was derived. It was rather difficult to determine whether this material has really suffered deformation, whether it was intruded during deformation, or whether it was intruded after deformation, following the contortions of an already deformed structure. Detailed study may show, therefore, that some of these rocks should be classed with the gneisses, if they prove to have suffered deformation. No doubt some of the pegmatitic injections accompanied the regional metamorphism. Others are thought to have been associated with certain injection gneisses whose relative age is not yet known.

There are many bodies of pink granite that are clearly later than the regional metamorphism. Perhaps the latest outburst of pegmatitic activity accompanied or closely followed the intrusion of these granites. The pegmatites of this latest outburst cut every group of rock in the Granite Gorge and record the latest decipherable event in the igneous activity of Archean time. Some of these pink granitic intrusives are usually visible, from whatever point the visitor may view the inner canyon. Because of their wide distribution and conspicuous appearance the name Granite Gorge is not inappropriate, although pure granite is far from being the most abundant rock in the gorge.

The following summary, by Lindgren,[3] of the igneous activity in the Cordilleran region in pre-Cambrian time is of interest in comparison with the present study of the Archean in the Grand Canyon. The agreement seems close enough to show that when the igneous history of the pre-Cambrian in the Grand Canyon is unraveled it will be found to differ little from that of the great region of which the Grand Canyon district is a part.

Pre-Beltian:
- Granitic gneisses (oldest); restricted areas.
- Surface lavas and tuffs; restricted areas.
- Granitic intrusions, now gneisses; small areas.
- Basic intrusions; small areas.
- Granitic intrusions; very large areas.
- Pegmatitic intrusions; large areas.

Beltian: Diabase intrusions, probably with basalt flows; small areas.

The pre-Beltian of Lindgren is the Archean of the Grand Canyon. The Beltian is the Algonkian Grand Canyon series; it is made up in the Grand Canyon, as elsewhere, of diabase intrusions and basalt flows.

The Archean complex of the Grand Canyon is now known as the Vishnu schist in the usage of the United States Geological Survey. It is evident, however, from the present study that the name includes two or more very different series of rocks. Doubtless it will be advisable at some future time to restrict the name Vishnu schist to the mica schist series and give another name or names to the gneisses, but until a more detailed study is made a change in the present usage would be premature.

[1] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, p. 24, 1903.

[2] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: U. S. Geol. Survey Bull. 397, p. 29, 1909.

[3] Lindgren, Waldemar, The igneous geology of the Cordilleras and its problems: Problems of American geology, p. 246, Yale University Press, 1915.

NORTH AMERICAN UPPER CRETACEOUS CORALS OF THE GENUS MICRABACIA.

By Lloyd William Stephenson.

INTRODUCTION.

Corals are meagerly represented in the Upper Cretaceous deposits of North America, and much of the material is in a poor state of preservation and can not be satisfactorily identified, either generically or specifically. It is important, therefore, to place on record descriptions and illustrations of some well-preserved corals of the genus Micrabacia from the Atlantic and Gulf Coastal Plain and from the western interior of the United States. The specimens from the Coastal Plain, with the exception of those from New Jersey and one lot from Mississippi, are in a much better state of preservation than those I have seen from either the western interior or Europe, though most of them are soft and to insure their safe handling it was found best to harden them with a dilute solution of white shellac.

Seven species and two varieties have been recognized. All are new with the exception of *Micrabacia americana* Meek and Hayden, which was originally described from poorly preserved specimens found in South Dakota. They are all represented by small, free, disk-shaped, simple (that is, not colony forming) corallites, not exceeding 10 millimeters in diameter. On account of their small size it is necessary to study the specimens under a lens of moderately high power, and to figure them adequately it is necessary to enlarge them four to eight times.

One of the new species, *M. cribraria*, occurs in the upper part of the Black Creek formation in North Carolina and the lower part of the Ripley formation in Alabama. Poorly preserved specimens, questionably referred to this species, have been found in the lower part of the Selma chalk in Mississippi, and specimens in a still poorer state of preservation but apparently having the same type of basal sculpture occur in the Woodbury clay in New Jersey. The strata exposed at all these localities are of approximately the same age and occur in the upper part of the zone of *Exogyra ponderosa*, a fossil zone which has been traced from New Jersey to Mexico. So far as known, therefore, this species is confined within narrow stratigraphic limits and will probably prove to be a valuable index fossil.

All the other Atlantic and Gulf coast species occur in the zone of *Exogyra costata*, which overlies the *Exogyra ponderosa* zone and which also has been traced from New Jersey to Mexico. *Micrabacia americana* Meek and Hayden and its variety *multicostata* are found in the upper part of the Montana group of the western interior of the United States, in beds that correspond in age to the zone of *Exogyra costata*. None of these forms are known to have a very wide geographic range, but within faunal subprovinces they will probably prove to be useful horizon indicators.

Little is known of the race history of the genus. The oldest species referred to it is *M. beaumontii* Milne-Edwards and Haime, from the lower part of the Lower Cretaceous (Neocomian), Caussols, Department of Var, France. If this species was correctly identified the genus therefore ranges through the Cretaceous, but its pre-Cretaceous ancestors are unknown, and apparently it became extinct before the beginning of the Eocene.

The type species of the genus is *M. coronula* (Goldfuss), from the chalk of Essen, Germany. Milne-Edwards and Haime [1] have described one species, *M. beaumontii*, from the Neocomian of

[1] Annales sci. nat., 3d ser., vol. 15, p. 90, 1851.

Caussols, Department of Var, France; Duncan[1] has described a species, *M. fittoni*, from the Gault (Albian) of Folkestone, England; and Bölsche[2] has described a species, *M. senoniensis*, from the Upper Senonian of Gehrden, Germany, where it is associated with *Belemnitella mucronata* Schlotheim. I have compared the American material with typical specimens of the type species, *M. coronula* (Goldfuss), and have confirmed their generic identity. Examples of *M. beaumontii*, *M. fittoni*, and *M. senoniensis* are not available for comparison, and the figures are poor, so that I have not been able to verify the correctness of their reference to Micrabacia.

In 1905 T. Wayland Vaughan (see synonymy, below) made the genus the type of the new family Micrabaciidæ, under which he also included the genera Diafungia Duncan, Microsmillia Koby, Podoseris Duncan, and Antilloseris Vaughan. This paper has been prepared under the supervision of Mr. Vaughan, to whom I am indebted for references to literature and for constructive criticism in regard to the generic relations, the classificatory value of the coral characters, and the use of terms.

Mr. T. W. Stanton has informed me of the stratigraphic position of the specimens from the western interior, most of which were inadequately labeled.

The specimens of Micrabacia from Maryland were collected by Messrs. Stanley Worden and M. I. Goldman; those from North Carolina, by me; those from the Chattahoochee region and Alabama, by Mr. Stanton and me; those from Mississippi, by me; those from Texas, by Mr. R. H. Bruce; and those from the western interior by Messrs. Stanton, F. H. Knowlton, Homer Squyer, H. M. Robinson, V. H. Barnett, C. J. Hares, C. E. Siebenthal, and W. C. Knight.

[1] British fossil corals, 2d ser., pt. 2, p. 37, pl. 14, figs. 6-9: Paleontographical Society, vol. 23, 1870.

[2] Deutsch. geol. Gesell. Zeitschr., Band 18, pp. 472, 473, pl. 9, fig. 1, 1866.

SYSTEMATIC DESCRIPTIONS.

Genus MICRABACIA Milne-Edwards and Haime.

1816. Cyclolites. William Smith (not Lamarck), Strata identified by organic fossils, p. 15.

1826. Fungia. Goldfuss, Petrefacta Germaniæ, vol. 1, p. 50, pl. 14, fig. 10.

1840. Fungia. F. A. Roemer (not Lamarck), Die Versteinerungen des norddeutschen Kreidegebirges, p. 25.

1849. Micrabacia. Milne-Edwards and Haime, Compt. Rend. Paris Acad. Sci., vol. 29, p. 71.

1850. Micrabacia. Milne-Edwards and Haime, A monograph of the British fossil corals, p. xlvii, Paleontographical Society.

1851. Micrabacia. Milne-Edwards and Haime, Annales sci. nat., 3d ser., Zoologie, vol. 15, p. 88.

1860. Micrabacia. Milne-Edwards, Histoire naturelle des coralliaires, vol. 3, p. 29 (amended).

1869. Micrabacia. Duncan, A monograph of the British fossil corals, 2d ser., pt. 2, p. 24, Paleontographical Society, vol. 22.

1876. Micrabacia. Meek and Hayden, A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country: U. S. Geol. and Geog. Survey Terr. Rept., vol. 9, p. 1.

1884. Micrabacia. Duncan, Linnean Soc. London Jour., Zoology, vol. 18, p. 143.

1905. Micrabacia. Vaughan, U. S. Nat. Mus. Proc., vol. 28, p. 387.

Type species, *Fungia coronula* Goldfuss.

The most complete previous description of the genus is that given by Duncan:

Corallum simple, free, lenticular, broader than high, convex above, slightly concave at the base, which has a circular outline. Calice with a small shallow axial depression, filled by a false columella, from which the principal septa radiate, being joined with those of the higher orders toward the circumference. Septa numerous, solid, imperforate, arched above, with a perpendicular outer edge. Costæ distinct on the base, bifurcating at the edge, a process from two costæ forming a septum. Intercostal spaces continuous with the line of direction of the septa, crossed by synapticula in concentric rows, and perforate between the synapticula. Interseptal loculi crossed by large and small synapticula, which radiate from the base in discontinuous lines, bounding canalicular spaces continuous below with the intercostal openings and above with the interseptal loculi high up. Costæ granular. Septa crenulate or minutely denticulate.

Key to species of the genus Micrabacia.[1]

Costæ absent in a sievelike central area of the base, which includes about 60 per cent of the basal diameter. Denticulations on septal edges ten to 1 millimeter........................ *M. cribaria* Stephenson (p. 117, Pl. XX, figs. 1–3).
Costæ extending to center of base:
  Costæ of last cycle long (20 to 30 per cent of diameter in adults), thick at terminus:
    Costæ acute, denticulate:
      Costæ 96.................................... *M. americana* Meek and Hayden (p. 118, Pl. XX, figs. 4–5).
      Costæ more than 96.................. *M. americana* var. *multicostata* Stephenson (p. 119, Pl. XX, fig. 6).
    Costæ smooth. Denticulations on septal edges eight or nine to 1 millimeter.
      M. rotatilis Stephenson (p. 119, Pl. XXI, figs. 1–4).
    Costæ faintly beaded. Denticulations on septal edges nine or ten to 1 millimeter.
      M. rotatilis var. *georgiana* Stephenson (p. 120, Pl. XXI, figs. 5–8).
  Costæ of last cycle short (7 to 18 per cent of diameter of base), thin at terminus:
    Costæ subacute, distinctly denticulate:
      Denticulations of costæ medium coarse. Corallum relatively high; sides steep. Denticulations on septal edges ten to 1 millimeter.................. *M. hilgardi* Stephenson (p. 120, Pl. XXII, figs. 1–6).
      Denticulations of costæ coarser than in *M. hilgardi*. Corallum large; sides evenly rounded. Septal edges alternate in prominence on the sides. Denticulations on septal edges ten to 1 millimeter.
        M. marylandica Stephenson (p. 121, Pl. XXII, figs. 7–10).
      Denticulations of costæ coarse. Denticulations on septal edges twelve to 1 millimeter. Lengths of costæ of last cycle more irregular and average length greater than in the two preceding species.
        M. mineolensis Stephenson (p. 122, Pl. XXIII, figs. 6–8).
    Costæ flattish, faintly beaded:
      Corallum low, sides straight, inclined inward. Denticulations on septal edges eleven or twelve to 1 millimeter............................ *M. mississippiensis* Stephenson (p. 123, Pl. XXIII, figs. 9–11).
      Corallum high, sides nearly or quite vertical. Denticulations on septal margins seven to 1 millimeter.
        M. coronula Goldfuss (p. 124, Pl. XXIII, figs. 1–5).

Micrabacia cribraria Stephenson, n. sp.

Plate XX, figures 1–3.

Corallum subdiscoidal; base nearly flat, upper surface convex, with axial depression slightly less than 1 millimeter deep. Dimensions of the type: Diameter 6.5 millimeters, height 2.5 millimeters.

The under side of the wall or base to a radial distance from the center of about 2 millimeters is irregularly tuberculated and presents numerous sievelike perforations roughly arranged in radial rows corresponding to the positions of the septa. The rough central area merges into a costate marginal band, the costæ numbering 96 and alternating with the septa. The costæ are thicker than the intercostal loculi, are roughly tuberculated, and on the periphery project prowlike somewhat beyond the edges of the septa. In each intercostal loculus are synapticulæ separated by elongated perforations.

The septa are thin and form five complete cycles, arranged in six groups, one group in each of the interspaces between the six primaries. Total number of septa 96. The secondaries extend to the columella; the tertiaries fuse against the secondaries near the columella; the two outer quaternaries of the group fuse against the tertiaries nearer the center than the two inner ones; the two outer quinaries of each of the two subgroups formed about the tertiaries fuse against the quaternaries nearer the center than the two inner quinaries of each subgroup. The primary septa are slightly higher than the members of the higher cycles, and their upper margins curve sharply downward into the central depression; the secondaries are slightly lower than the primaries, and the tertiaries, quaternaries, and quinaries each become progressively slightly lower. The margins of the septa are finely denticulate, the number being about ten to 1 millimeter. Synapticulæ are numerous; striæ are present on the sides of the septæ at the upper margins, apparently arranged fanlike, though only partly exposed.

Columella elliptical in cross section, spongy, trabecular, a certain number of the trabeculæ terminating in more or less scattered, irregularly distributed papillæ; length of cross section about one-fifth the diameter; width about one-tenth the diameter.

This species differs from the other species of American Micrabacia in the arrangement of the basal costæ, which instead of extending to the center merge into a perforated, irregularly calcified, noncostate, sievelike area.

[1] Excluding the species *M. beaumontii* Milne-Edwards and Haime, *M. fittoni* Duncan, and *M. senoniensis* Bölsche, the descriptions of which are inadequate.

Type.—Collection of the United States National Museum, catalogue No. 31996. From Whiteley Creek Landing, Neuse River, N. C. (5354).[1]

Distribution.—North Carolina: Snow Hill marl member of Black Creek formation (upper part of *Exogyra ponderosa* zone), Whiteley Creek Landing, Neuse River (5354); Kerrs Cove, Black River (5362). Alabama: Lower part of Ripley formation (upper part of *Exogyra ponderosa* zone), Union Springs at "Conecuh Falls" (6820); Central of Georgia Railway cut half a mile west of Union Springs (6815). Mississippi: Lower part of Selma chalk (upper part of *Exogyra ponderosa* zone), questionably on the Tupelo road 8 miles west of Fulton, Lee County (6452).

Micrabacia americana Meek and Hayden.

Plate XX, figures 4–5.

1860. *Microbacia coronula.* Meek and Hayden, Philadelphia Acad. Nat. Sci. Proc., vol. 12, p. 430 (not *M. coronula*, Milne-Edwards and Haime).

1876. *Micrabacia americana.* Meek and Hayden, A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country: U. S. Geol. and Geog. Survey Terr. Rept., vol. 9, p. 1, pl. 28, figs. 1a–d.

The description given in the second paper cited above is as follows:

Corallum small, subplano-convex, or slightly concave below, and convex with a rather deep central depression above. Intercostal foramina of the mural disk oval and numerous. Rays or costæ of the under side straight, about 12 in the middle, but bifurcating so as to number near 100 around the periphery, apparently denticulate. Septa few at the center, but increasing by the intercalation of smaller ones between, so as to equal the number of costæ, with which they alternate on the periphery, very finely and sharply denticulate on the upper and lateral edges.

This description can hardly be improved so far as the type material is concerned, but that material is so poorly preserved as scarcely to permit satisfactory identification of other material with it. The number of costæ is probably 96 on the periphery, and the grouping of the costæ and septa is probably the same as in all the species described in this paper, with the exception of *M. americana* var. *multicostata*, which has a greater number of costæ and a slightly modified arrangement of the costæ within the groups.

Specimens from one locality in Wyoming and several localities in Montana, all from the upper part of the Montana group, are referred to this species, and one of them with well-preserved costæ, associated in the same piece of rock with *M. americana* var. *multicostata*, is figured in Plate XX, figure 4. In this figured specimen the costæ, which number 96, are arranged in six groups, 16 in a group; they are acute, becoming thicker on the periphery, and are distinctly and rather finely denticulate. The bifurcations of the separate cycles are at irregular distances from the center; the costæ of the highest cycle are relatively long (1.5 to 2 millimeters), in this respect resembling those of *M. rotatilis*. The synapticulæ in the intercostal loculi extending to the center number 12 or more and are separated by radially elongated perforations. The synapticulæ and perforations are not definitely arranged in concentric rows. Other fragments in the same matrix indicate that the septa are thin and correspond in number to the costæ, with which they alternate; on the sides of the septa are striæ and rows of synapticulæ and tubercles radiating fanlike from a point near the base of the columella. The septa are attached to the wall by a row of synapticulæ that connect with the intercostal synapticulæ.

The strongly denticulate costæ serve to distinguish this species from *M. rotatilis* and *M. rotatilis* var. *georgiana*, its nearest allies in the Coastal Plain.

Type.—Collection of United States National Museum, Catalogue No. 456. From Moreau River, S. Dak.

Occurrence.—Fox Hills sandstone, Moreau River, S. Dak. (U. S. N. M. catalogue No. 456); questionably identified from the Bearpaw shale, Forsyth project, sec. 26, T. 1 N., R. 34 E., Montana (8133); questionably identified from the Pierre shale (upper part), 4 miles northeast of Moorcroft, Wyo. (7208); questionably identified from the Montana group (probably upper part), 20 miles southwest of Mingusville, Mont. (Homer Squyer collection, U. S. N. M. catalogue No. 22976); and from "Montana," probably from the Montana group (upper part), and perhaps from the locality 20 miles southwest of Mingusville (Homer Squyer collection, U. S. N. M. catalogue No. 21896).

Range.—Upper part of the Montana group, including the upper part of the Pierre shale and the Fox Hills sandstone.

[1] Numbers in parentheses refer to United States Geological Survey collection numbers, unless otherwise indicated.

Micrabacia americana var. multicostata Stephenson, n. var.

Plate XX, figure 6.

This variety is based on one specimen 7 millimeters in diameter, showing only the under side of the wall (base). In the same matrix are other specimens and fragments which probably belong to *M. americana* Meek and Hayden. The costæ are acute, sharply defined, distinctly and finely denticulate and number 123 at the periphery; two costæ fail to reach the margin, being suppressed or crowded out by adjacent ones. In general appearance the sculpture of the base resembles that of *M. americana* Meek and Hayden. The costæ are separable into six groups, but the number of costæ extending to the margins of the group is not uniform, some of the cycles not being complete. The number of costæ in the six groups taken in succession about the disk are 22, 22, 20, 22, 19, and 18; one costa is crowded out in each of the last two groups. The bifurcations of each cycle are at very irregular distances from the center. The intercostal loculi are crossed by synapticulæ, which in the loculi extending to the center number 12 or more. The synapticulæ are separated by radially elongated perforations.

This variety differs from all the known species of Micrabacia in that it possesses 123 instead of 96 costæ. The lack of uniformity in the number of costæ in the groups and the obvious crowding out of one costa in each of two groups suggests that the type specimen may be abnormal. The fact that three of the six groups of costæ number 22 suggests that the total number of costæ in a normal specimen would be 132, though this would mean at least one incomplete cycle of costæ.

Type.—Collection of United States National Museum, catalogue No. 31997.

Occurrence.—Cretaceous of "Montana," probably from the upper part of the Montana group, and perhaps from the locality 20 miles southwest of Mingusville (Homer Squyer collection).

Micrabacia rotatilis Stephenson.

Plate XXI, figures 1–4.

1916. *Micrabacia rotatilis.* Stephenson, Maryland Geol. Survey, Upper Cretaceous, pp. 753–755, pl. 49, figs. 1–4.

Corallum subdiscoidal; moderately high, with flat to rather strongly concave base; sides steep below, rounding evenly into the subflattish top; axial depression 1.5 to 2 millimeters deep. Dimensions of the type: Diameter 9 millimeters, height about 4 millimeters.

The costæ on the base are thin and sharply defined and alternate with the septa; they start with six at the center and by successive bifurcations increase to 96 on the periphery; they are nearly smooth and increase slightly in thickness from the center to the periphery. The costæ are in six groups corresponding to the groups of septa. Each group starts with one costa (first cycle), which bifurcates near the center to form two costæ (second cycle); these bifurcate 0.5 millimeter from the center to form four costæ (third cycle); the four bifurcate about 1 millimeter from the center and produce eight costæ (fourth cycle); and the eight bifurcate 1.5 to 2 millimeters from the center, producing 16 costæ (fifth cyle); in the last cycle the bifurcations producing the two outer and the two middle pairs of the group take place nearer the center than those of the other four pairs; in the largest specimens the pairs of costæ in the last cycle are 2.5 to 3 millimeters long. The ends of the costæ are prowlike but scarcely project beyond the edges of the septa. The intercostal loculi are narrow and are crossed by small synapticulæ separated by radially elongated perforations; in the type the perforations in the intercostal loculi extending to the center number 18; the intercostal synapticulæ and perforations are roughly arranged in concentric rows.

The septa are thin and form five complete cycles arranged in six groups, one group in each of the interspaces between the primary septa. Total number of septa 96. The secondaries extend to the columella; the tertiaries fuse against the secondaries near the columella; the two outer quaternaries of the group fuse against the tertiaries nearer the center than the two inner ones; the two outer quinaries of each of the subgroups formed about the tertiaries fuse against the quaternaries nearer the center than the two inner ones. The primary septa are a little higher than the members of the higher cycles, and the septa of each of the succeeding cycles appear to be a little lower than those of the preceding cycles. The edges of the septa are finely and distinctly denticulate, the number of denticulations being eight or nine to 1 millimeter; the inner edges of the primaries and secondaries are bifid, each presenting a troughlike depression with serrated margins descending to the top of the columella; sides of septa with striæ, tubercles, and rows of synapticulæ radiating fanlike from a point near the base of the columella. Each septum is joined to the wall (base) by synapticulæ that connect with the intercostal synapticulæ. These are separated by perforations that connect with the intercostal perforations.

Columella elliptical in cross section, spongy, trabecular, some of the trabeculæ terminating above in more or less scattered, irregularly distributed small papillæ; length of cross section about one-sixth the diameter; width about one-twentieth the diameter.

This species differs from other species of Micrabacia from the Coastal Plain in the greater sharpness and smoothness of the basal costæ, the greater irregularity in the distance of the bifurcations of the several cycles from the center, the greater length of the costæ of the last cycle, the greater number of intercostal perforations, and the greater size attained by the adults. It is distinguishable from *M. rotatilis* var. *georgiana* by its smoother and slightly thicker costæ. *M. americana* Meek and Hayden and its variety, *multicostata*, have more strongly denticulate bases. In *M. coronula* (Goldfuss), of the European Cretaceous, the denticulations of the septal edges are markedly coarser than those of any of the American species.

Type.—Collection of the Maryland Geological Survey, on deposit in the United States National Museum. From a locality seven-eighths of a mile southwest of Brightseat, Md.

Distribution.—Prince Georges County, Md., Monmouth formation (*Exogyra costata* zone), bed of small branch about seven-eighths of a mile southwest of Brightseat and three-eighths of a mile south of the Sheriff road; near McNeys Corners, about a mile west of Friendly; questionably near Seat Pleasant.

Range.—The three localities enumerated are within the *Exogyra costata* zone.

Micrabacia rotatilis var. georgiana Stephenson, n. var.

Plate XXI, figures 5–8.

This variety is based on four nearly complete specimens and several fragments from Mercers Mill Creek near Georgetown, Quitman County, Ga., which possess most of the specific characters of *M. rotatilis* except that the costæ are thinner and sharper, producing a more open effect, and instead of being nearly smooth are rather faintly denticulated, though strongly enough to produce a rougher appearance than that of the more typical members of the species. The synapticulæ on the sides of the septa seem also to be a little coarser, and there is a tendency for the striæ to be replaced by rows of small tubercles. The number of denticulations on the margins of the septa is nine or ten to 1 millimeter. Dimensions of the type (Pl. XXI, figs. 5–7): Diameter, 6.5 millimeters; height, 2.75 millimeters.

Type.—Collection of United States National Museum, catalogue No. 31998.

Occurrence.—Upper part of Ripley formation (upper part of *Exogyra costata* zone), Mercers Mill Creek near Georgetown, Quitman County, Ga. (5417).

Micrabacia hilgardi Stephenson, n. sp.

Plate XXII, figures 1–6.

Corallum somewhat variable, but in general moderately high, subdiscoidal, with steep, only slightly convex sides, suggesting a truncated cone; base flat, slightly convex or slightly concave; axial depression small and about 1 millimeter deep in the type, with steep sides. Dimensions of the type (Pl. XXII, figs. 4–6): Diameter 5.5 millimeters, height 3 millimeters.

The costæ on the base or wall start with six and by successive bifurcations reach 96 on the periphery; they alternate with the septa. Each of the six original costæ (first cycle) is the focus of a group; the original divides near the center into two (second cycle); these split about 0.5 millimeter from the center to form four (third cycle); the four split 1.25 to 1.5 millimeters from the center to form eight (fourth cycle); and finally the eight split on the periphery to form 16 (fifth cycle). The bifurcations of each cycle are at rather markedly irregular distances from the center. Up to the fourth cycle the costæ are coarsely denticulate; those of the last cycle are thin, sharp, and finely denticulate, and form a narrow band bordering the periphery; they project slightly beyond the periphery. In the narrow intercostal loculi are synapticulæ numbering 12 in the loculi extending to the center, separated by slightly elongated perforations; the intercostal synapticulæ and perforations are arranged in concentric rows.

The septa are thin and are separable into six groups, each group occupying the interspace between two of the six primaries. Total number of septa 96. The secondaries extend to the columella; the tertiaries are fused against the secondaries near the columella; the two outer quaternaries of each group are fused against the tertiaries nearer the center than the two inner ones; and the two outer quinaries of each subgroup formed about the tertiaries are fused against the quaternaries nearer the center than the two inner ones. The primary septa are slightly higher than the secondaries, and their inner edges descend steeply to the top of the columella; the members of each of the succeeding cycles are slightly lower than those of the preceding cycles. Margins of the septa finely denticulate, the denticulations numbering about twelve to 1 millimeter. Sides of septa with striæ, tubercles, and synapticulæ radiating fanlike from a point near the base of the columella. Each septum is joined to the wall (base) by synapticulæ that connect with the intercostal synapticulæ; these are separated by perforations that connect with the intercostal perforations.

Columella elliptical, spongy, trabecular, certain of the trabeculæ terminating above in more or less scattered, irregularly distributed papillæ; length of the cross section a little less than one-fifth the diameter; width a little less than one-tenth the diameter.

This species differs from *M. marylandica* in size and form, being smaller and having straighter sides, which incline slightly more toward the center; the costæ are not quite so thick, the costal denticulations are a little finer, the bifurcations of the separate cycles are at more irregular distances from the center, and the edges of the septa on the sides of the corallum do not alternate in prominence. In *M. cribraria* the corallum is flatter and only the outer cycle of basal costæ are clearly distinguishable, the other cycles being obscured by calcification; in *M. rotatilis* the corallum is flatter and the costæ are thinner, sharper, and much smoother, and the costæ of the last cycle are much longer; in *M. americana* Meek and Hayden the corallum is flatter, the basal costæ are thinner, and the costæ of the last cycle are much longer and not so thin at the extremities; in *M. mississippiensis* the corallum is flatter, the basal costæ are thinner and smoother, and the bifurcations of the separate cycles are at less regular distances from the center. In the European species *M. coronula* (Goldfuss) the denticulations on the margins of the septa are markedly coarser.

Type.—Collection of United States National Museum, catalogue No. 32001. From Lee's old mill site, Union County, Miss. (6873). Named in honor of Prof. E. W. Hilgard, former State geologist of Mississippi.

Distribution.—Mississippi: Ripley formation (*Exogyra costata* zone), Lee's old mill site, 2 miles northeast of Keownville, Union County (6873). Chattahoochee region: Upper part of Ripley formation (*Exogyra costata* zone), Eufaula, Ala. (854); Mercers Mill Creek near Georgetown, Ga. (5417); Chattahoochee River, 2 miles below Eufaula (857).

Range.—*Exogyra costata* zone.

Micrabacia marylandica Stephenson.

Plate XXII, figures 7–10.

1916. *Micrabacia marylandica.* Stephenson, Maryland Geol. Survey, Upper Cretaceous, pp. 755–757, pl. 48, figs. 1–4.

This species is based on seven good specimens and a few fragments from the Monmouth formation of Maryland.

Corallum low to moderately high, subdiscoidal, base flat or slightly convex, top evenly convex with a small axial depression about 1.25 millimeters deep in the type. Dimensions of the type (Pl. XXII, fig. 10): Diameter 7 millimeters, height 3 millimeters.

The under side of the base or wall is ornamented with a system of radiating bifurcating costæ which alternate with the septa; the system starts with six costa, which by successive bifurcations form cycles of 12, 24, 48, and 96 costæ. Each of the original six costæ (first cycle) is the focus of a group; the original of each group splits near the center into two (second cycle); these split 0.5 millimeter from the center into four (third cycle); about 1.5 to 1.75 millimeters from the center the four costæ divide, to form eight (fourth cycle); and about 2.5 millimeters from the center in the type the eight divide, producing 16 costæ (fifth cycle) on the outer rim. The bifurcations of each cycle are at nearly equal distances from the center. The costæ up to the fourth cycle are relatively thick and coarsely nodular; those of the last cycle are thin, finely denticulate, and form a band about 0.75 millimeter wide, bordering the outer margin; they appear not to project beyond the edges of the septa. The intercostal loculi are very narrow and are occupied by 12 or 13 synapticulæ separated by perforations, most of which are slightly elongated radially; the synapticulæ and perforations are arranged in concentric rows.

The septa are very thin and are arranged in six groups, one group in each of the interspaces between the primary septa. Total number of septa 96. The secondaries extend to the columella; the tertiaries fuse against the secondaries near the columella; the two outer quaternaries of the group fuse against the tertiaries nearer the center than the two inner ones; in each of the two subgroups formed about the tertiaries the two outer quinaries fuse against the quaternaries nearer the center than the two inner ones. The primary septa are slightly higher than the members of the higher cycles, which appear to be of about equal height. On the sides of the corallum the septa distinctly alternate in prominence. Margins of the septa finely denticulate, the number of denticulations being about ten to 1 millimeter. Sides of septa with striæ and rows of synapticulæ and tubercles radiating from a point near the base of the columella.

Columella elliptical, spongy, trabecular, some of the trabeculæ terminating in more or less scattered, irregularly distributed, small papillæ; length of cross section between one-fifth and one-sixth the diameter; width about one-tenth the diameter.

Micrabacia hilgardi differs from this species in size, form, and ornamentation of the base; its corallum is smaller, the sides straighter and more inclined, and the septal edges on the sides of the corallum do not alternate in prominence; the bifurcations of its separate cycles of costæ are at more irregular distances from the center, and the costæ are thinner and more finely denticulate. In *M. cribraria* the costæ and perforations of the base are largely obscured by irregular calcification, and the costæ project more prominently on the periphery. In *M. mississippiensis* the basal costæ are narrower, smoother, and flatter, the bifurcations of each cycle are more irregularly spaced with reference to the center, and the profile of the side of the corallum is not so steep and is slightly truncated. In *M. rotatilis* the basal costæ are thinner, sharper, and much smoother. In *M. americana* Meek and Hayden the costæ are narrower and sharper, and the bifurcations producing the last cycle are much nearer the center and at less regular distances from the center. In *M. coronula* (Goldfuss) the corallum is higher and the septal denticulations coarser.

Type.—Collection of the Maryland Geological Survey, on deposit in the United States National Museum. Found seven-eighths of a mile southwest of Brightseat, Prince Georges County, Md.

Occurrence.—Monmouth formation (*Exogyra costata* zone), bed of small branch seven-eighths of a mile southwest of Brightseat and three-eighths of a mile south of the Sheriff road, Prince Georges County, Md.; half a mile west of Friendly, Prince Georges County, Md.

Micrabacia mineolensis Stephenson, n. sp.

Plate XXIII, figures 6–8.

The description of this species is based on two imperfect specimens, of which the one shown in Plate XXIII, figure 6, is taken as the type.

The corallum is crushed in both specimens but appears to be of moderate height, with steep to nearly vertical, gently convex sides; axial depression of moderate size and about 0.75 millimeter deep in the type; base slightly concave in both specimens. Dimensions of the type: Diameter 5.5 millimeters, height 2.5 millimeters (?).

The costæ on the base start with six at the center and by successive bifurcations reach 96 on the periphery; they alternate with the septa. The costæ are in six groups, each group having as its focus one of the original six costæ (first cycle); the original divides near the center into two (second cycle); the two divide about 0.5 millimeter from the center to form four (third cycle); these divide about 1 to 1.25 millimeters from the center to form eight (fourth cycle); and the eight divide 1.25 to 2 millimeters from the center to form 16 (fifth cycle). The costæ of the fifth cycle are 0.75 to 1.5 millimeters long. The bifurcations forming the costæ of the third, fourth, and fifth cycles are at rather markedly irregular distances from the center. Up to and including the fourth cycle the costæ are thick and coarsely denticulate; those of the fifth cycle are thin, sharp, and finely denticulate and project a little beyond the edges of the septa. The interseptal synapticulæ, which number 12 or 13 in the loculi extending to the center, are separated by radially elongated perforations.

The septa are thin and are separable into six groups, each group occupying the interspace between two of the six primaries. Total number of septa 96. The secondaries extend to the columella; the tertiaries fuse against the secondaries near the columella; the two outside quaternaries of each group fuse against the tertiaries nearer the center than the two inner quaternaries; and the two outside quinaries of each subgroup formed about the tertiaries are fused against the quaternaries nearer the center than the two inner ones. The primary septa are slightly more prominent than the secondaries, their inner edges descending steeply to the top of the columella; the members of each of the succeeding cycles appear to be slightly lower than those of the preceding ones. Margins of the septa finely denticulate, the beads numbering 12 to 1 millimeter. Sides of septa not uncovered.

Columella elliptical, the length of the cross section at the top being about one-fifth the diameter and the width about one-tenth the diameter. The columella is spongy and trabecular, certain of the trabeculæ terminating above in more or less scattered, irregularly distributed papillæ.

This species is most nearly related to *M. hilgardi* and *M. marylandica*, from which it may be distinguished by its coarser and more roughly denticulated base and by the greater average length of the costæ of the last cycle.

Type.—Collection of United States National Museum, catalogue No. 32006.

Occurrence.—Probably Navarro formation (*Exogyra costata* zone), well of Hoard Oil & Gas Co., 7 miles east of Mineola, Wood County, Tex.; collected at a depth of 3,146 to 3,160 feet (9369).

Micrabacia mississippiensis Stephenson, n. sp.

Plate XXIII, figures 9-11.

This species is based on one specimen from the Ripley formation of Mississippi. Corallum low, subdiscoidal, with flat base, moderately steep, slightly convex sides, and axial depression about 0.75 millimeter deep. Dimensions: Diameter, 6 millimeters; height, 2 millimeters.

Under side of wall (base) ornamented with sharply defined, moderately thick, flattish, coarsely but rather faintly nodular costæ which alternate with the septa; they start with six at the center and by successive bifurcations reach 96 on the periphery. Each of the original six costæ is the center of a group. The original (first cycle) of the group divides near the center into two (second cycle), and these divide to form four (third cycle) at less than 0.5 millimeter from the center; of the four costæ the two outside ones divide about 1 millimeter and the two inside ones about 1.5 millimeters from the center, forming eight (fourth cycle); of the eight costæ the two outside ones divide about 1.75 millimeters, the two middle ones about 2.25 millimeters, and the other four about 2.5 millimeters from the center, forming 16 (fifth cycle). The distances of the bifurcations of each cycle from the center are thus rather markedly irregular. The costæ of the last cycle are thinner than those of the lower cycles, their ends are prowlike, and they project slightly beyond the septa. The narrow intercostal loculi are crossed by concentrically arranged synapticulæ numbering 12 or 13 in the loculi extending to the center; the synapticulæ are separated by radially elongated perforations.

The septa are thin and are arranged in six groups with six primaries and four complete higher cycles, making a total of 96 on the periphery. Each group occupies one of the interspaces between two of the primaries. The secondaries extend to the columella; the tertiaries are fused to the secondaries near the columella; the two outside quaternaries of each group are fused to the tertiaries nearer the center than the two inner ones; in each of the subgroups formed about the tertiaries the two outer quinaries are fused against the quaternaries nearer the center than the two inner ones. The primary septa are slightly higher than the members of the higher cycles, and those of each of the succeeding cycles are slightly lower than those of the preceding cycles. The margins of the septa are set with beadlike denticulations, the number being about 11 or 12 to 1 millimeter. The inner edges of the primaries where they descend to the top of the columella are set with a double row of denticulations. The sides of the septa are not well exposed except in one small area near the top, on which are rows of prominent tubercles radiating fanlike from within.

Columella elliptical in cross section, spongy, trabecular, some of the trabeculæ terminating in more or less scattered, irregularly distributed nodular processes. Length of cross section about one-sixth the diameter; width about one-tenth the diameter.

The other American species of Micrabacia differ from this species in the following characters: In *M. cribraria* the irregular calcification has obscured all but the last cycle of basal costæ; the corallum of *M. hilgardi* is higher, the sides are steeper, and the costæ of the last cycle are shorter; in *M. marylandica* the bifurcations of the separate cycles of costæ are at more regular distances from the center, and the average length of the costæ of the last cycle is less; in *M. americana* Meek and Hayden and *M. rotatilis* the costæ are thinner and sharper, and the costæ of the last cycle are markedly longer. The septal denticulations of *M. coronula* (Goldfuss) of the European Cretaceous are coarser than in any of the American species.

Type.—Collection of United States National Museum, catalogue No. 32008.

Occurrence.—Ripley formation (*Exogyra costata* zone), Lee's old mill site, 2 miles northeast of Keownville, Union County, Miss. (6873).

Micrabacia coronula (Goldfuss).

Plate XXIII, figures 1–5.

1826. *Fungia coronula.* Goldfuss, Petrefacta Germaniæ, vol. 1, p. 50, pl. 14, fig. 10.

1840. *Fungia coronula.* F. A. Roemer, Die Versteinerungen des norddeutschen Kreidegebirges, p. 25.

1849. *Micrabacia coronula.* Milne-Edwards and Haime, Compt. Rend., vol. 29, p. 71.

1850. *Micrabacia coronula.* Milne-Edwards and Haime, A monograph of the British fossil corals, p. 60, pl. 10, figs. 4, 4a-c (with a synonymy), Paleontographical Society.

1860. *Micrabacia coronula.* Milne-Edwards, Histoire naturelle des coralliaires, vol. 2, p. 29 (with synonymy).

1862. *Fungia coronula.* Goldfuss, Petrefacta Germaniæ, 2d ed., vol. 1, p. 47, pl. 14, fig. 10.

1884. Micrabacia. Duncan, Linnean Soc. London Jour., Zoology, vol. 18, p. 143.

1905. Micrabacia. Vaughan, U. S. Nat. Mus. Proc., vol. 28, p. 387 (Duncan's description quoted).

An account and illustrations of *Micrabacia coronula* (Goldfuss) are included for purposes of reference and comparison. The description of Milne-Edwards and Haime is quoted in full below:

> Corallum simple, lenticular, short; its under surface horizontal or slightly concave; its upper surface somewhat convex. Mural disk completely naked and regularly perforated by small intercostal pores. Costæ closely set, almost straight, equally narrow, not prominent, and but slightly echinulated; only 12 of them arise in the center of the disk, but these soon bifurcate, and the 24 costæ so formed soon divide again; at about half the distance from the center to the circumference of the disk each costa bifurcates once more, and the two terminal costæ so formed are grouped two by two toward the periphery of the disk. The granulations which form all these costæ are not very distinct and are arranged in single lines. Calicular fossula small and not very deep, but well marked and rather elongated laterally. Columella very small, oblong, and subpapillose. Septa forming five complete cycla, and corresponding to the intercostal spaces; those of the last cyclum quite rudimentary; the others tall, thin, straight, and united by subspiniform trabiculæ. Those of the first cyclum larger than the others and augmenting slightly in thickness toward the middle; the secondary ones almost as large; all delicately denticulated along their upper edge, and much thinner toward their outer and inferior angle than in any other part. Diameter, three or sometimes four lines; height, one line and a half.
>
> The above-described fossils were found in the Greensand at Warminster, in Wiltshire, and according to William Smith, who was the first author that mentions this fossil, are also met with at Chute Farm and Puddle Hill, near Dunstable.
>
> By an attentive comparison with the specimens decribed by Goldfuss and belonging to the Poppelsdorff Museum at Bonn, we have ascertained the specific identity of this British coral with the *Fungia coronula* found in the chalk of Essen. Specimens exist in Mr. Bowerbank's cabinet and in the collections belonging to the Geological Society, the Museum of Paris, the Museum of Bonn, and M. Defrance at Sceaux, who has designated it by the unpublished name of *Fungia dubia.*

Duncan's description of the genus, which amounts to a nearly complete description of the species, is quoted on page 116. To these descriptions I may add that, as in the American species, the septa probably start with six instead of 12, and by successive intercalations in four additional complete cycles increase to 96 in the adult. Likewise the basal costæ start with six and by successive bifurcations in five complete cycles reach 96 on the periphery.

Compared with the American forms the denticulations on the edges of the septa are somewhat coarser (seven to 1 millimeter), the axial depression is shallower, the adults attain a larger size, and, though somewhat variable in form, the profile is in general more nearly vertical on the sides.

The specimens in the two lots indicated below, which are supposed to be typical of *M. coronula* (Goldfuss), are in very different states of preservation; those from the British Museum are filled with matrix; those from Holland are free from matrix, but the costæ are missing and the margins of the septa are imperfect, so that they are scarcely specifically identifiable with the other material.

Distribution.—According to Goldfuss the species occurs in the "Mergelgrand" at Essen, Prussia, and Milne-Edwards and Haime state that in England it occurs in the [upper] Greensand (Albian). (See quotation, p. 124.) Milne-Edwards gives the occurrence and distribution as "Group de la craie tuffeau: Le Maus, Essen, Warminster." Specimens in the collection of the United States National Museum are labeled as follows:

U. S. N. M. Cat. No. 155214. Folx-les-Caves, Holland, Cretaceous, Group de la craie tuffeau.

U. S. N. M. Cat. No. 156436. Obtained from the British Museum (no locality given).

Three specimens from the first locality, figured on Plate XXIII, figures 3, 4, and 5, are renumbered catalogue Nos. 32002 and 32003; two specimens from the second lot, figured on Plate XXIII, figures 1 and 2, are renumbered catalogue Nos. 32004 and 32005.

UNIDENTIFIED SPECIMENS OF MICRABACIA.

Specimens of Micrabacia too poorly preserved for satisfactory specific identification have been found in the western interior at the following localities: Pierre shale (upper part), 5 miles southwest of Marmarth, N. Dak. (7971), and about 3 miles southeast of Moorcroft, Wyo., approximately 75 feet below the Fox Hills sandstone (6520); Montana group (upper part), Old Cooper Creek Crossing, Laramie Plains, Wyo. (U. S. N. M. catalogue No. 28528); Montana group (upper part), Ben Gaugh's ranch, Cooper Creek, 20 miles northwest of Laramie, Wyo. (3479).

Specimens of Micrabacia referred by Weller[1] to *M. americana* Meek and Hayden have been found in New Jersey at the following localities:

Merchantville clay, near Matawan; Woodbury clay, Lorillard, near Matawan and near Haddonfield; Wenonah sand, near Crawfords Corner.

Through the courtesy of Dr. H. B. Kümmel I have examined Weller's figured specimens from the Woodbury clay near Lorillard, and the lots from the Woodbury clay and from the Merchantville clay near Matawan, all of which appear to be too poorly preserved for satisfactory specific identification. Squeezes made from prints of the bases of the specimens from Lorillard suggest the type of sculpture exhibited by *M. cribraria* rather than that of *M. americana.*

Dr. Weller states, in a letter recently received, that the material from Haddonfield examined by him was in the collection of the Academy of Natural Sciences of Philadelphia. Dr. H. A. Pilsbry, in response to a letter of inquiry, states that he can not find these specimens in the collection, and apparently they have been lost, a most unfortunate circumstance, because, according to Dr. Weller, they were preserved intact, and not in the form of molds, as were the other New Jersey specimens.

[1] Weller, Stuart, Cretaceous paleontology of New Jersey: New Jersey Geol. Survey, Paleontology, vol. 4, p. 271, pl. 5, figs. 14-17, 1907.

PLATES XX-XXIII.

PLATE XX.

Micrabacia cribraria Stephenson, n. sp. (p. 117).

FIGURE 1. Calicular view of the type, × 4, from the Snow Hill marl member of the Black Creek formation (upper part of *Exogyra ponderosa* zone), Whiteley Creek Landing, Neuse River, N. C. (U. S. G. S. collection 5354; U. S. N. M. catalogue No. 31996.) The periphery and margins of all the septa are imperfect.

2. Side view of the type, × 8; the upper portions of the septal edges are imperfect.

3. Basal view of the type, × 8; the ends of the costæ and portions of the surface are imperfect.

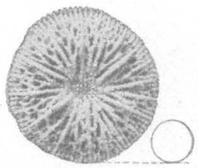
Micrabacia americana Meek and Hayden (p. 118).

FIGURE 4. Basal view of a specimen, × 8, from "Montana," probably from the upper part of the Montana group, and perhaps from a locality 20 miles southwest of Mingusville. (Homer Squyer collection, U. S. N. M. catalogue No. 21896.)

5. View of a broken specimen in the same collection, partly restored by retouching, showing the profile through the center and faint indications of the characters on the sides of the septa. (U. S. N. M. catalogue No. 21896.)

Micrabacia americana var. multicostata Stephenson, n. var. (p. 118).

FIGURE 6. Basal view of the type, × 8, from "Montana," probably from the upper part of the Montana group, and perhaps from a locality 20 miles southwest of Mingusville. (Homer Squyer collection, U. S. N. M. catalogue No. 31997.)



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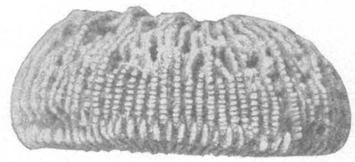

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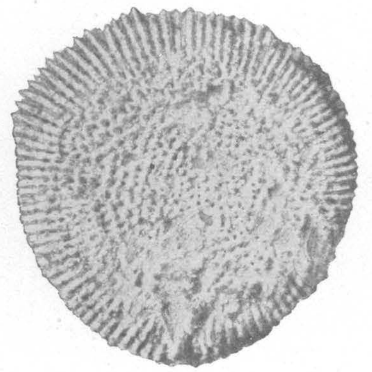

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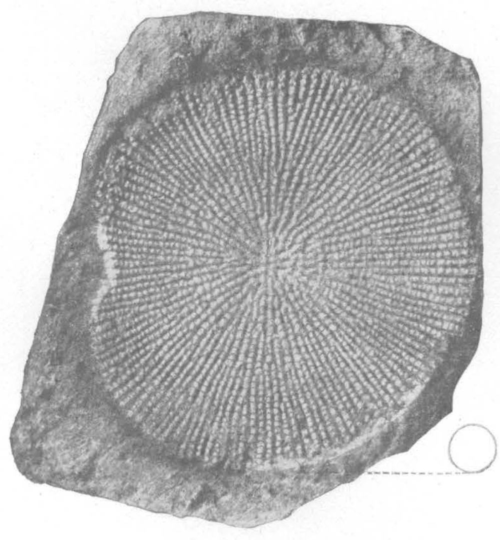

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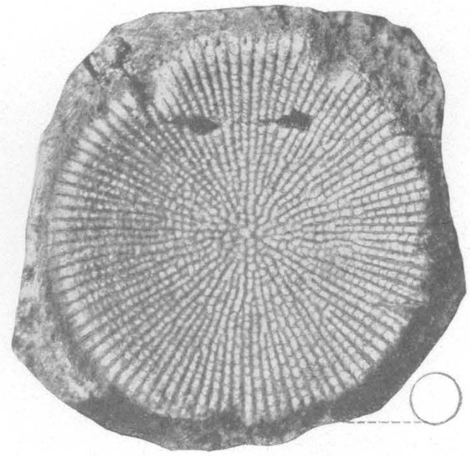

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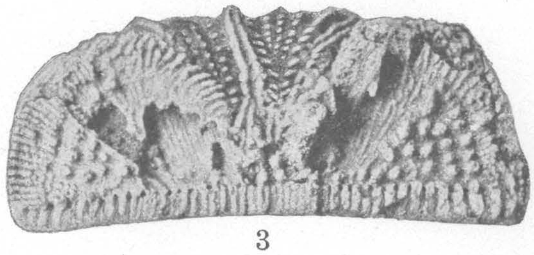
SPECIES OF MICRABACIA.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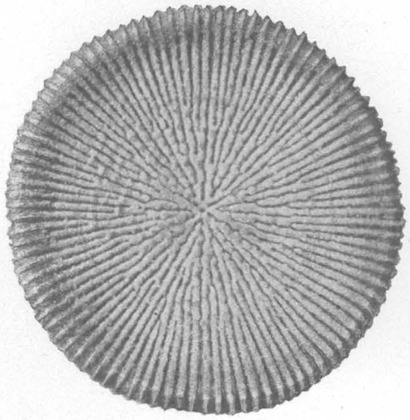
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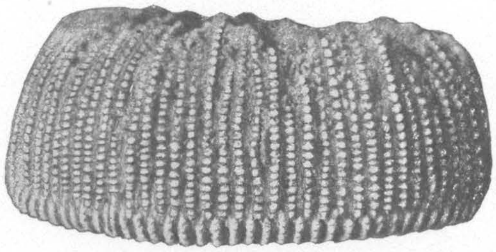
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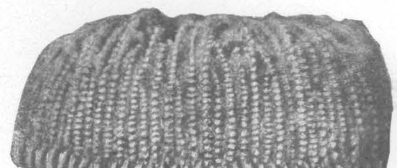
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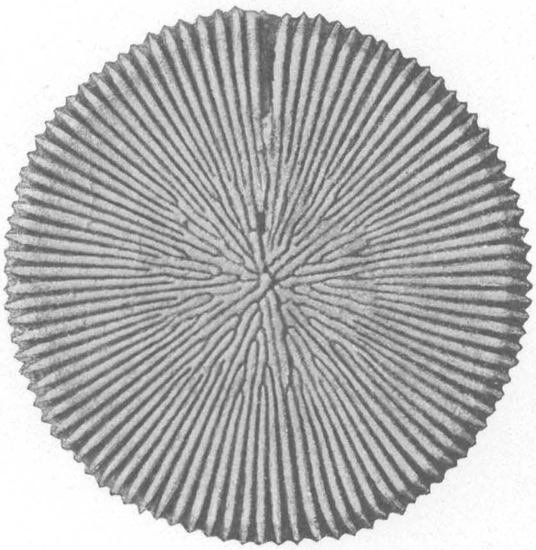
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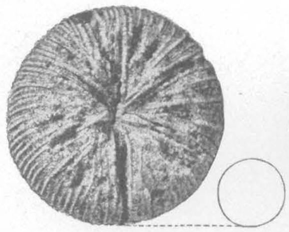
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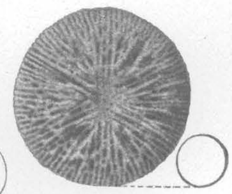
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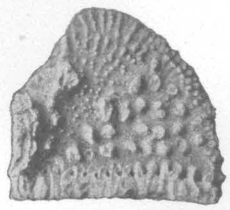
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SPECIES OF MICRABACIA.

PLATE XXI.

Micrabacia rotatilis Stephenson (p. 119).

FIGURE 1. Calicular view of the type, × 4, from the Monmouth formation (*Exogyra costata* zone), bed of a small branch about seven-eighths of a mile southwest of Brightseat, and three-eighths of a mile south of the Sheriff road, Prince Georges County, Md. (Collection of the Maryland Geological Survey, on deposit in the United States National Museum.) The septal edges are imperfect and the interseptal loculi are filled with matrix.

2. Side view of the type, × 8; the interseptal loculi are filled with matrix and the upper part of the corallum is imperfect.

3. Vertical internal cross section of the type, × 8; broken through the center, showing the sides of septa, the spongy columella, and the intercostal perforations of the base.

4. Basal view of the type, × 8, showing the character and grouping of the costæ.

Micrabacia rotatilis var. georgiana Stephenson, n. var. (p. 120).

FIGURE 5. Calicular view of the type, × 4, from the upper part of the Ripley formation (*Exogyra costata* zone), Mercers Mill Creek near Georgetown, Ga. (U. S. G. S. collection 5417; U. S. N. M. catalogue No. 31998.) The upper edges of the septa are imperfect.

6. Side view of the type, × 8; the interseptal loculi are filled with matrix, and the upper part of the corallum is imperfect.

7. Basal view of the type, × 8, showing the character and grouping of the septa.

8. Vertical internal cross section of a fragmentary specimen from the type locality (U. S. G. S. collection 5417; U. S. N. M catalogue No. 31999), showing the side of a septum and the intercostal perforations of the base.

PLATE XXII.

Micrabacia hilgardi Stephenson, n. sp. (p. 120).

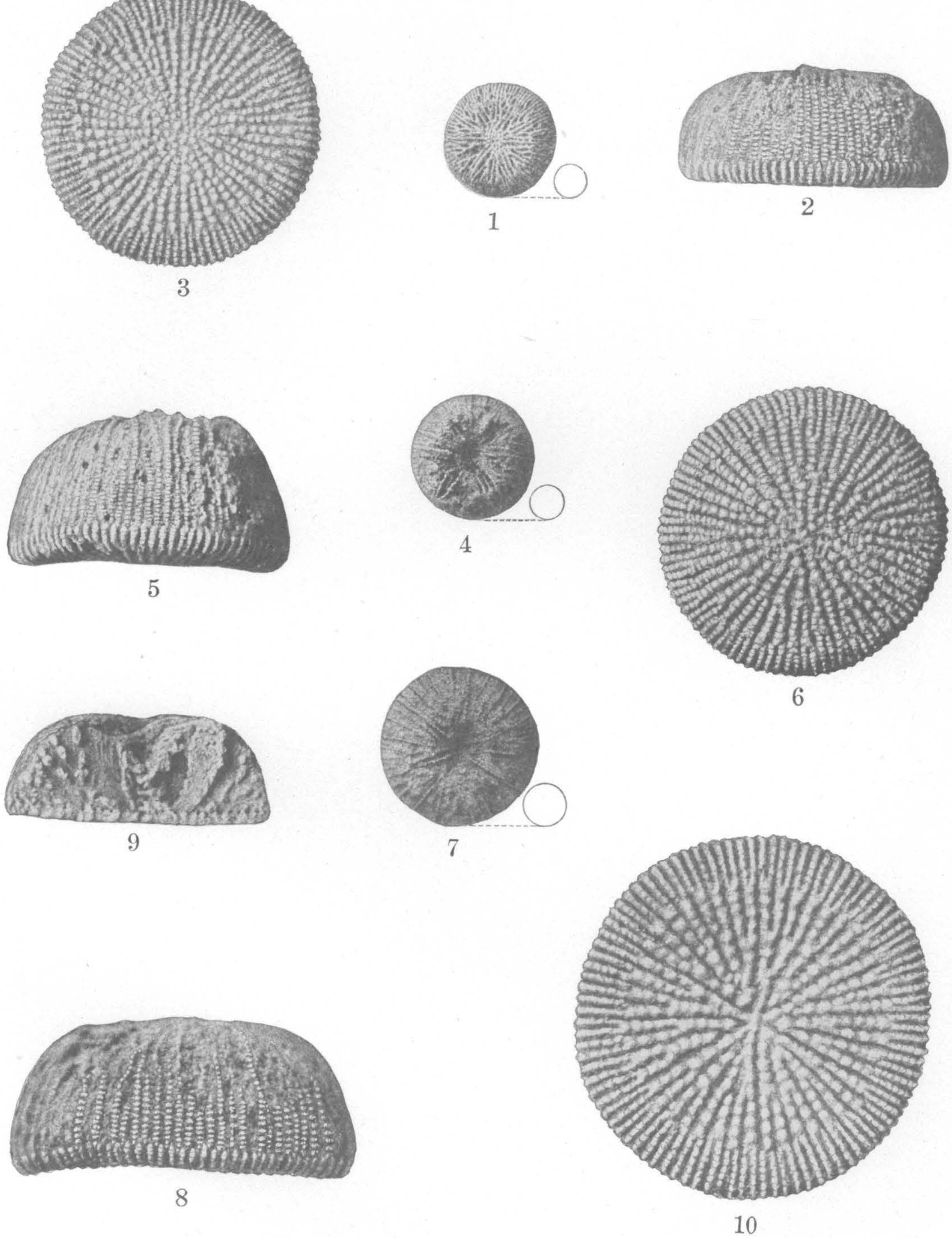
FIGURE 1. Calicular view, × 4, of a specimen from the upper part of the Ripley formation (*Exogyra costata* zone), Mercers Mill Creek near Georgetown, Quitman County, Ga. (U. S. G. S. collection 5417; U. S. N. M. catalogue No. 32000.) The upper edges of the septa are imperfect.

2. Side view of the same specimen, × 8, showing the septal margins and the prowlike ends of the costæ.
3. Basal view of the same specimen, showing the character and grouping of the costæ.
4. Calicular view of the type, × 4, from the Ripley formation (*Exogyra costata* zone), Lee's old mill site, 2 miles northeast of Keownville, Union County, Miss. (U. S. G. S. collection 6873; U. S. N. M. catalogue No. 32001.) The edges of the septa are imperfect and the interseptal loculi are filled with matrix.
5. Side view of the type, × 8, showing the septal edges and the prowlike ends of the costæ.
6. Basal view of the type, × 8, showing the character and grouping of the costæ.

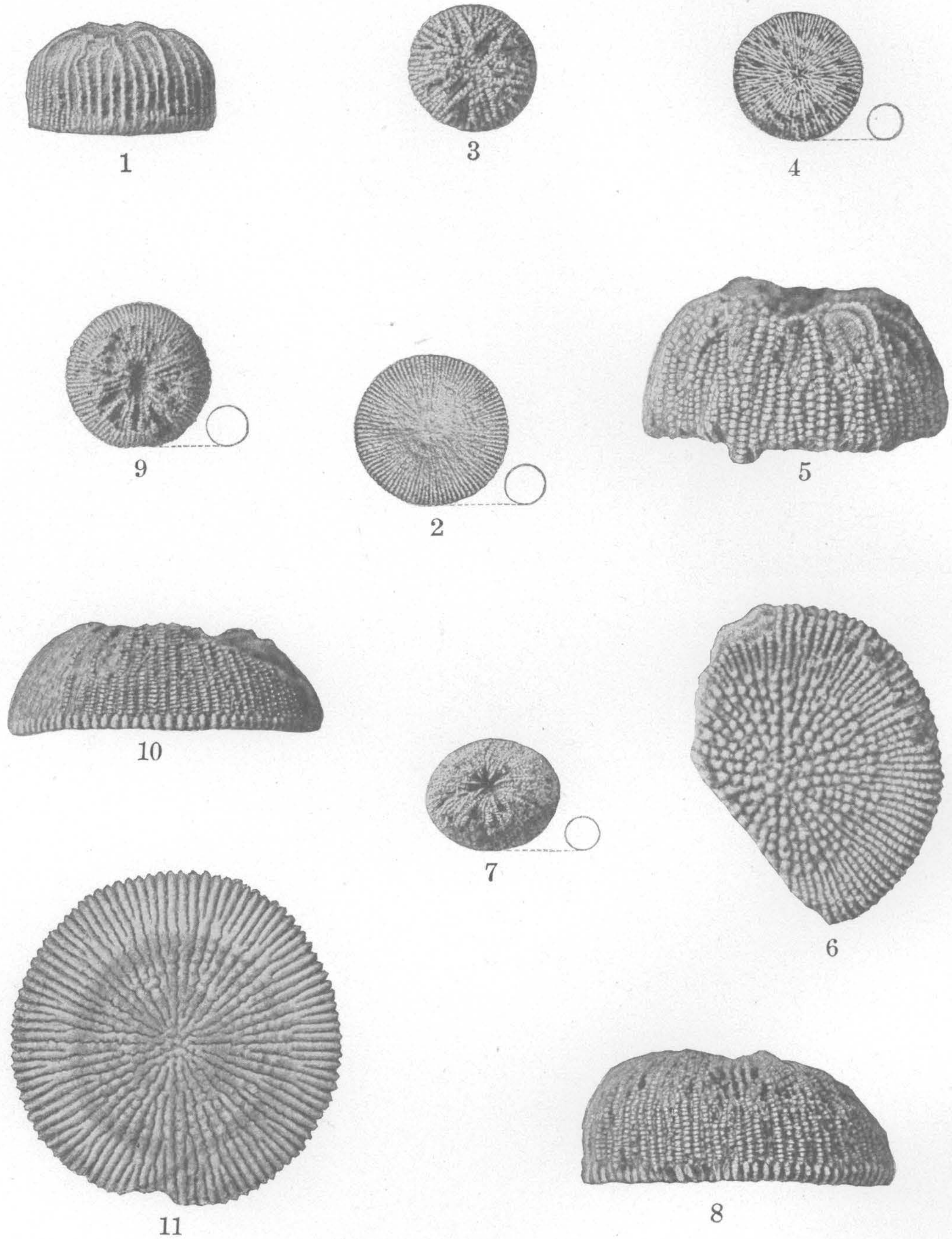
Micrabacia marylandica Stephenson (p. 121).

FIGURE 7. Calicular view of a specimen, × 4, from the Monmouth formation (*Exogyra costata* zone), bed of a small branch about seven-eighths of a mile southwest of Brightseat, and three-eighths of a mile south of the Sheriff road, Prince Georges County, Md. (Collection of the Maryland Geological Survey, on deposit in the United States National Museum.) The edges of the septa are imperfect and the interseptal loculi are filled with matrix.

8. Side of the same specimen, × 8, showing the septal edges and the prowlike ends of the costæ.
9. Vertical cross section of a specimen, × 8, in the same collection, showing the sides of the septa, the spongy columella, and the intercostal perforations of the base.
10. Basal view of the type, × 8, in the same collection, showing the character and grouping of the costæ.



SPECIES OF MICRABACIA.



SPECIES OF MICRABACIA.

PLATE XXIII.

Micrabacia coronula (Goldfuss) (p. 124).

FIGURE 1. Side view of a specimen, × 4, from the British Museum, locality not stated on the label. The septal edges are imperfect and the interseptal loculi are filled with matrix. (U. S. N. M. catalogue No. 32004.)

2. Basal view of a specimen, × 4, from the same locality. (U. S. N. M. catalogue No. 32005). The costæ are very much worn and imperfect.

3, 4. Calicular view and basal view, × 4, of a specimen from the "Cretaceous, Group de la craie tuffeau, Folx-les-Caves, Holland." (U. S. N. M. catalogue No. 32002.) The edges of the septa are imperfect, and the costæ are gone from the base, leaving only the lower edges of the septa showing.

5. Side view of a specimen, × 4, from the same locality. (U. S. N. M. catalogue No. 32003.) The ends of the costæ are missing.

Micrabacia mineolensis Stephenson, n. sp. (p. 122).

FIGURE 6. Basal view of the type, × 8, from the Navarro formation (?), well of Hoard Oil & Gas Co., 7 miles east of Mineola, Wood County, Tex., collected at a depth of 3,146-3,160 feet. (U. S. G. S. collection 9369; U. S. N. M. catalogue No. 32006.) Shows the character and grouping of the costæ.

7. Calicular view of a crushed specimen, × 4, in the same collection. (U. S. N. M. catalogue No. 32007.)

8. Side view of the specimen illustrated in figure 7; shows the septal edges and the prowlike ends of the basal costæ.

Micrabacia mississippiensis Stephenson, n. sp. (p. 123).

FIGURE 9. Calicular view of the type, × 4, from the Ripley formation (*Exogyra costata* zone), Lee's old mill site, 2 miles northeast of Keownville, Union County, Miss. (U. S. G. S. collection 6873; U. S. N. M. catalogue No. 32008.) The upper edges of the septa are imperfect.

10. Side view of the type, × 8, showing the septal edges and the prowlike ends of the costæ.

11. Basal view of the type, × 8, showing the character and grouping of the costæ.

SOME PALEOZOIC SECTIONS IN ARIZONA AND THEIR CORRELATION.

By Frederick Leslie Ransome.

PURPOSE AND SCOPE OF PAPER.

During the last 16 years detailed geologic work has been done in a number of mining districts in Arizona, several reconnaissance reports have added to our knowledge of the geology of the State, and sections of Paleozoic and older rocks in the Grand Canyon and at Globe, Ray, Clifton, Tombstone, and Bisbee have been carefully studied; but hitherto the investigations in most of these fields have been unconnected by reconnaissance examinations of intervening areas. Realization of this lack of correlation led, in 1912, to a preliminary reconnaissance of the country extending northwestward from Globe to Jerome, in the hope that light might thereby be thrown on the nature of the changes that connect the well-known stratigraphic section of the Grand Canyon with the very different succession of beds at Globe. A visit to the Santa Catalina Range, northeast of Tucson, in company with Prof. C. F. Tolman, jr., who is preparing the Tucson folio for the United States Geological Survey, afforded an opportunity of partly closing the gap of terra incognita between Ray and Tombstone. Detailed work on the Ray quadrangle, the full results of which are not yet published, has supplied the materials for a much more accurate description of the geologic column in central Arizona than was heretofore possible, and similar work in the Tombstone district has extended the Bisbee section northward. Finally, some additional reconnaissance has been made of the Mazatzal Range and the Sierra Ancha.

The present paper includes (1) a brief introductory outline of the broad topographic features of the State, (2) a description of the full and very satisfactorily exposed geologic section of the Ray-Globe region, with less detailed accounts, in part abstracted from the literature, of other stratigraphic sections to the southeast and northwest, and (3) a discussion of the correlation of these sections from the Grand Canyon, in the northwestern part of the State, to Bisbee, near the Mexican border.

The positions of the sections discussed may be seen by reference to the outline map (Pl. XXIV) and to the diagram accompanying the correlation chart (Pl. XXV, p. 136).

TOPOGRAPHIC PROVINCES OF ARIZONA.

The State of Arizona may conveniently be divided into three topographic regions—the plateau region, the mountain region, and the desert or bolson region. The plateau region, which has an area of about 45,000 square miles, occupies the northeastern part of the State and drains generally northward through the Little Colorado and smaller streams into the Grand Canyon. The general altitude of this region, which is a portion of the great Colorado Plateau, ranges from 7,000 to over 8,500 feet. As Dutton graphically describes it,

> Its strata are very nearly horizontal, and with the exception of Cataract Canyon and some of its tributaries it is not deeply scored. Low mesas, gently rolling and usually clad with an ample growth of pine, piñon, and cedar; broad and shallow valleys, yellow with sand or gray with sage, repeat themselves over the entire area.

Here and there the Kaibab (Pennsylvanian) limestone, the prevalent surface rock, is covered by flows of basalt or bears erosion remnants of younger strata, and above it, north of Flagstaff, rise the lofty extinct volcanoes of the San Francisco Mountains.

The southwestern limit of the plateau traverses the State in a general southeasterly direction from the Grand Wash Cliffs, near the eastern border of Nevada, to the New Mexico line, a few miles northeast of Clifton.[1] This

[1] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, p. 14, 1882.

boundary along much of its course is a single bold cliff 2,000 feet or more in height, but elsewhere it is less definite or simple, owing to a distribution of the total difference in relief among a series of great topographic steps or to local accumulations of volcanic rocks, especially basalt. In general the outer or lower line of cliffs separates nearly horizontal and undisturbed strata on the northeast from faulted and tilted beds on the southwest, and locally, as along the Grand Wash Cliffs, this line is itself a fault scarp, more or less modified by erosion.

The Grand Wash Cliffs rise precipitously 3,000 feet or more above the plains to the west. According to Lee,[1] pre-Cambrian granite is exposed at their base and the Redwall limestone forms their crest and the floor of the adjacent plateau. About 45 miles east of the Music Mountains a second gigantic step, that of the Aubrey Cliffs, north of Seligman,[2] carries the geologic section nearly to the top of the Kaibab (Pennsylvanian) limestone, which forms the surface of the Coconino Plateau, south of the Grand Canyon. South of the Music Mountains there is another ample terrace in the ascent from the valleys of the mountain region to the Colorado Plateau—that of the Truxton Plateau. This bench, which lies between the Cottonwood and Aquarius cliffs to the west and the Yampai Cliffs and Juniper Mountains to the northeast, is described by Lee[3] as a granitic peneplain partly covered with volcanic rocks.

South of Ash Fork the continuity of the plateau escarpment is interrupted by flows of basalt that poured down from the plateau to the valley of the Verde, forming a slope that has been utilized by the Santa Fe, Prescott & Phoenix Railway between Ash Fork and Jerome Junction. East of this railway and north of Jerome the edge of the plateau is in general a scarp (part of the Aubrey Cliff of Gilbert[4]) over 2,000 feet in total height, with deep reentrants and bold pinnacled promontories. East of Camp Verde a thick series of basaltic flows with associated tuffs has covered the edges of the nearly horizontal sedimentary rocks; but these beds appear again at the head of Fossil Creek and continue eastward past Payson in the great southward-facing cliff that marks the descent of about 2,000 feet from the Mogollon Mesa to the Tonto Basin. From Fort Apache eastward to the New Mexico line the plateau boundary becomes less distinct. Erosion has partly destroyed its continuity, and vast accumulations of volcanic rock have obscured the original plateau surface.

The second topographic division, the mountain region, which adjoins the plateau region on the southwest, is essentially a broad zone of short nearly parallel ranges, among which are the Dragoon, Chiricahua, Whetstone, Pinaleno, Galiuro, Santa Catalina, Pinal, Superstition, Ancha, and Mazatzal, extending diagonally across the State from the southeast corner to Colorado River. The width of this zone may be taken as from 70 to 150 miles, but its southwest boundary is not susceptible of precise demarcation. Few of the individual ranges exceed 50 miles in length or 8,000 feet in altitude. Their general trend is almost northwest, but near the Mexican border it becomes more nearly north, and the mountain zone as a whole coalesces with a belt of north and south ranges that extends through New Mexico and borders the plateau region on the east.

Most of these ranges consist mainly of quartzites and limestones of Paleozoic or earlier age, resting with conspicuous unconformity upon granitic, gneissic, and schistose rocks. All these rocks are cut by later intrusives, especially by diabasic and monzonitic rocks, and are partly covered by flows of lava. Structurally these ranges are characterized by the dominant part played by faulting as compared with folding. The great copper deposits of Arizona, so far as they are known, are all, except that at Ajo, within this mountainous zone.

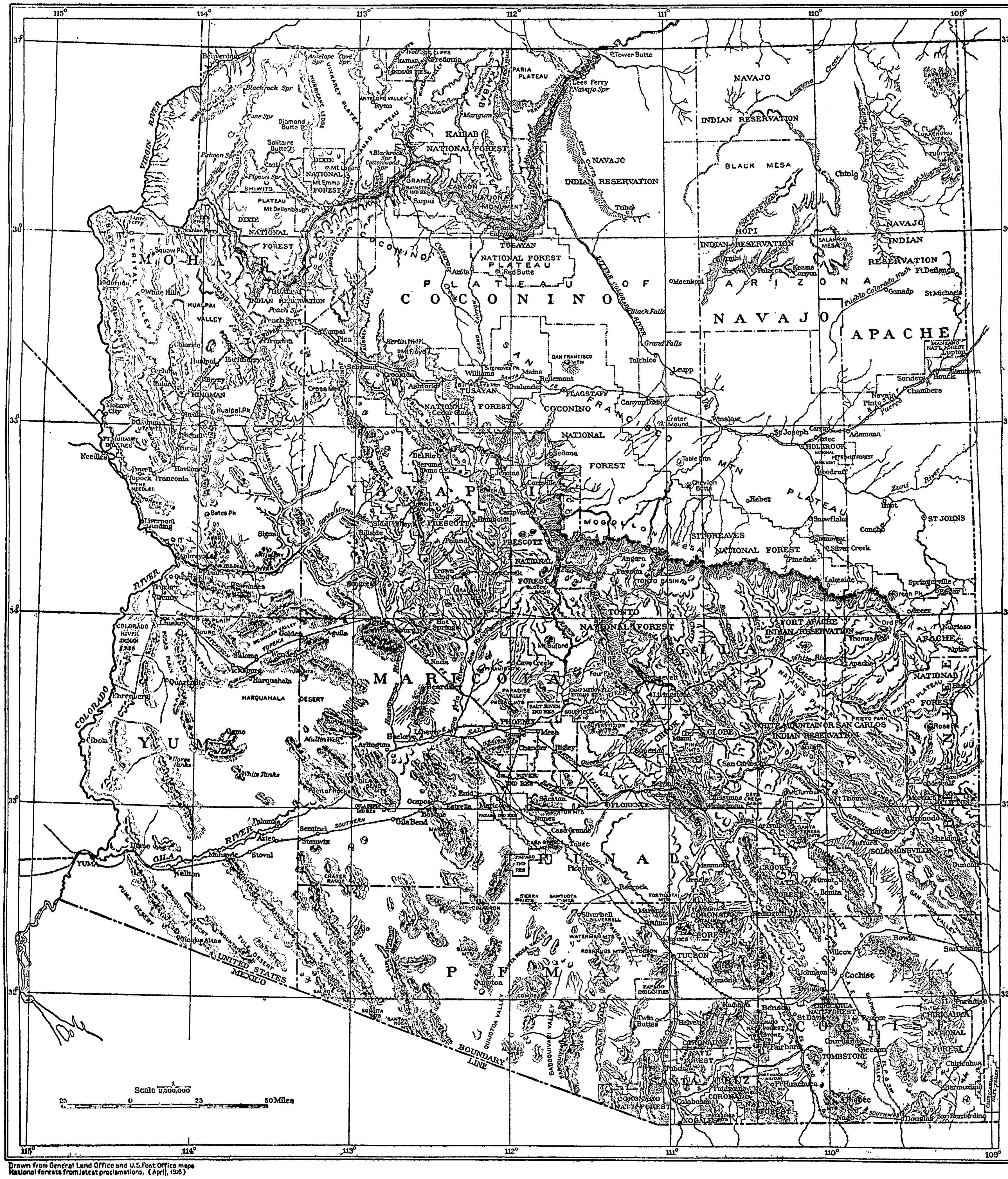
Adjoining the mountain region on the southwest is the third topographic division, the desert region, which also contains numerous short mountain ranges of prevalent northwesterly trend. In this region, however, most of the ranges are separated by broad desert plains underlain by fluviatile and lacustrine deposits of late geologic age, or by undulating granitic

[1] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, p. 19, pl. 1, 1908.

[2] See Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 8, pl. 1, 1910.

[3] Op. cit., p. 21.

[4] U. S. Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 49, 1875.



Drawn from General Land Office and U.S. Post Office maps
National forests from latest proclamations. (April, 1916)

MAP OF ARIZONA.

lowlands partly covered with gravels and flows of lava.[1] The boundary between the mountain and desert regions is, as previously stated, indefinite but may provisionally be taken as a curved line extending from Nogales, on the Mexican frontier, past Tucson and Phoenix to Needles, near the California line. The main drainage lines of both regions are transverse to the trend of the ranges, the run-off finding its way through Gila and Williams rivers into the Colorado. The minor streams, many of them intermittent, occupy in general the valleys between the parallel ranges.

RAY-GLOBE GEOLOGIC SECTION.

GENERAL FEATURES.

The Ray and Globe quadrangles, as may be seen from the diagram on Plate XXV, are in south-central Arizona, and the Ray quadrangle lies immediately south of the Globe quadrangle. They include the Pinal Range and parts of the smaller Mescal, Dripping Spring, and Tortilla ranges. The relative positions of these ranges are shown in the outline map of Plate XXIV. The rocks are intricately faulted, the fault pattern being on an extraordinarily minute scale, and the stratified rocks have been extensively invaded by diabase. Nevertheless, excellent sections, of the kind illustrated in Plate XXIX (p. 141), may be studied in the Mescal Range and in many of the larger fault blocks of the Dripping Spring Range. The total thickness of the beds below the base of the Carboniferous limestone and above the pre-Cambrian crystalline rocks is about 1,600 feet. The Carboniferous limestone is at least 1,000 feet thick and is limited above by a Mesozoic erosion surface. No evidence of angular unconformity has been detected within the Paleozoic sedimentary series in the Ray quadrangle, although the exposures are so good that any appreciable angular discordance could scarcely escape recognition.

PINAL SCHIST.

The Pinal schist and intrusive batholithic masses of granite and quartz-mica diorite are the fundamental rocks of the Ray-Globe region. The name Pinal schist was first applied in 1903[2] to the pre-Cambrian schistose terrane of the Globe quadrangle, the geographic term of the designation being derived from the Pinal Mountains, on whose slopes the schists are extensively exposed. As was then pointed out, these rocks probably correspond to what Blake[1] 20 years earlier had called the "Arizonian slates," but as the geographic term of his name did not accord with the principles of nomenclature followed by the Geological Survey and as his lithologic term was not appropriate for crystalline schists, that designation could not well be retained. Since the publication of the Globe report the name Pinal schist has been applied to the pre-Cambrian crystalline schists of the Clifton-Morenci[2] and Bisbee[3] districts. This formation has of late years attained economic importance as the principal country rock of the disseminated copper deposits at Ray and Miami.

Most of the Pinal schist is light gray to blue-gray in color and has a more or less satiny luster on the cleavage surface. In texture it ranges from cryptocrystalline slaty sericitic schist through fine-granular fissile rocks to imperfectly cleavable, coarsely crystalline quartz-muscovite schist carrying andalusite or sillimanite. The coarsely crystalline varieties occur chiefly in the vicinity of granitic intrusive masses and grade into the less intensely metamorphosed varieties that make up the bulk of the formation and are characteristic of most of the exposures in the Ray quadrangle.

In the vicinity of Ray and west of that town a considerable part of the schist is a gray fine-grained, moderately fissile rock that has the unmistakable aspect of a squeezed and metamorphosed sandstone. Thin sections of this variety, seen under the microscope, show rotund but irregular grains of quartz as much as 5 millimeters in diameter in a groundmass consisting chiefly of quartz and sericite. The large quartz grains show the effects of granulation with more or less recrystallization under pressure.

Associated with those schists that are clearly of sedimentary origin are very subordinate masses of greenstone schist and other varieties that were originally igneous material.

[1] Antisell, Thomas, U. S. Pacific R. R. Expl., vol. 7, pt. 2, pp. 130–138, 1857.

[2] Ransome, F. L., Geology and ore deposits of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, p. 23, 1903.

[1] Blake, W. P., Geology of the Silver King mine: Eng. and Min. Jour., vol. 35, pp. 238–239, 1883.

[2] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, p. 56, 1905.

[3] Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, p. 24, 1904.

SCANLAN CONGLOMERATE.

At the base of the sedimentary column at Ray (see Pl. XXV) is the Scanlan conglomerate, first described in the Globe report, where it was said to be from 1 to 6 feet thick and composed of imperfectly rounded pebbles of vein quartz with scattered flakes of schist held in a pink arkosic matrix. The Scanlan conglomerate is locally the most variable of all the Paleozoic formations, both in constitution and in thickness. It was evidently formed, with little transportation, from the materials that the waves of an advancing sea found lying on a well-worn ancient surface of low relief. Areas of schist were littered with fragments of white vein quartz, and the upper parts of granitic masses were deeply disintegrated. Consequently the basal conglomerate where it rests on the Pinal schist is composed chiefly of imperfectly rounded pebbles of quartz in a matrix of small particles of schist, grains of quartz, and flakes of mica; where it rests on granite or quartz-mica diorite the pebbles are also mostly quartz, but the matrix is arkosic and the layers of pebbles may be associated with deposits of arkose that in many places merge imperceptibly with the underlying massive rock or the overlying Pioneer shale. These two varieties of the conglomerate, however, are connected by transition facies. The thickness of the formation varies widely from place to place.

In some localities the base of the Pioneer shale may be marked only by a few sparsely distributed pebbles or the Scanlan conglomerate may not be recognizable at all. In others the conglomerate attains a thickness of fully 15 feet and carries abundant well-rounded pebbles, including a few of quartzite derived from some ancient formation that is not now exposed in this region. Above this well-defined bed, which locally resembles the younger Barnes conglomerate, and under the typical Pioneer shale is a coarse arkosic sandstone from 15 to 30 feet thick. Similar arkosic material accompanies the Scanlan conglomerate in other localities and marks a change in the conditions of deposition by which fine material was laid down instead of coarse. In the Barnes Peak section, in the northwestern part of the Globe quadrangle, the lower 25 feet of the Pioneer shale, above the Scanlan conglomerate, is sandy and arkosic.

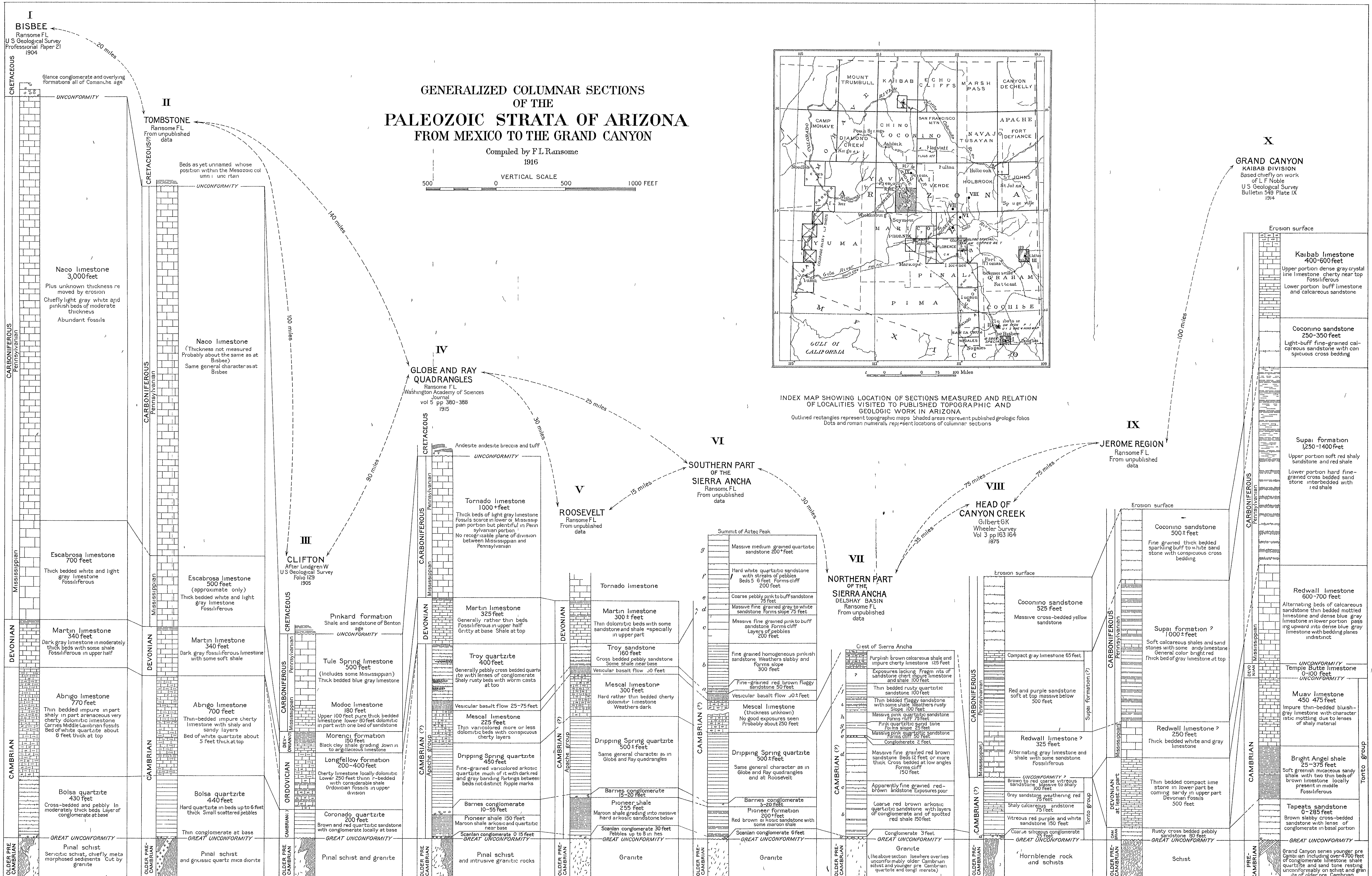
PIONEER SHALE.

In the Globe report the name Pioneer shale was given to a series of shaly beds that overlie the Scanlan conglomerate and underlie the Barnes conglomerate. The typical section is that exposed on the northeast slope of Pioneer Mountain.

In most places the Pioneer formation consists of dark reddish-brown, more or less arenaceous shales composed largely of fine arkosic detritus with little or no calcareous material. In some beds fragments of pink feldspar are easily recognizable with the unaided eye, and as a rule the shales toward their base grade into arkosic grits. These arkosic basal beds are well developed in the Apache Mountains, just northeast of the Globe quadrangle, where they attain a thickness of approximately 175 feet. Up to a horizon 75 feet above the granite the individual beds are thick, but above that thinner beds appear and these grade upward into the shale. Abundant round or elliptical spots, light buff or greenish in color, caused by local reduction and removal of the ferruginous pigment, are highly characteristic of the Pioneer shale, and in the absence of clear structural relations serve to distinguish that formation from certain similar beds in the stratigraphically higher Dripping Spring quartzite. Surfaces of fresh fracture generally sparkle with minute flakes of white mica.

Although the Pioneer shale is soft in comparison with the conglomerates and quartzites and weathers into smooth slopes, it is nevertheless a well-indurated, firm, and in places not very fissile rock. The general color of the formation as seen on the hill slopes is dark red, maroon, chocolate, or dull purplish gray.

In the Globe report the average thickness of the Pioneer shale was given as 200 feet, which is about the thickness at Pioneer, in the northeastern part of the Ray quadrangle. In the ravine west of Hackberry Spring, in the southwestern part of the Ray quadrangle, the shale is 100 feet thick. The average thickness for that quadrangle is accordingly estimated at about 150 feet. The Pioneer shale so far as known is not fossiliferous and presents no characteristics that mark it indubitably as marine or fluviatile in origin. It is believed to be marine and to have been deposited in shallow water. No mud cracks have been observed in it.


GENERALIZED COLUMNAR SECTIONS
OF THE
PALEOZOIC STRATA OF ARIZONA
FROM MEXICO TO THE GRAND CANYON
Compiled by F L Ransome
1916
VERTICAL SCALE
500 0 500 1000 FEET
I
BISBEE
Ransome F L
U S Geological Survey
Professional Paper 21
1904
20 miles
CRETACEOUS
Glance conglomerate and overlying formations all of Comanche age
UNCONFORMITY
Naco limestone
3,000 feet
Plus unknown thickness removed by erosion
Chiefly light gray white and pinkish beds of moderate thickness
Abundant fossils
CARBONIFEROUS
Pennsylvanian
Mississippian
Escabrosa limestone
700 feet
Thick bedded white and light gray limestone
Fossiliferous
DEVONIAN
Martin limestone
340 feet
Dark gray limestone in moderately thick beds with some shale
Fossiliferous in upper half
CAMBRIAN
Abrigo limestone
770 feet
Thin bedded impure in part shaly in part arenaceous very cherty dolomitic limestone
Carries Middle Cambrian fossils
Bed of white quartzite about 8 feet thick at top
Bolsa quartzite
430 feet
Cross-bedded and pebbly. In moderately thick beds. Layer of conglomerate at base
GREAT UNCONFORMITY
OLDER PRE CAMBRIAN
Pinal schist
Sericitic schist, chiefly metamorphosed sediments. Cut by granite
II
TOMBSTONE
Ransome F L
From unpublished data
CRETACEOUS(?)
Beds as yet unnamed whose position within the Mesozoic column is uncertain
UNCONFORMITY
Naco limestone
(Thickness not measured. Probably about the same as at Bisbee)
Same general character as at Bisbee
Escabrosa limestone
500 feet
(approximate only)
Thick bedded white and light gray limestone
Fossiliferous
Martin limestone
340 feet
Dark gray fossiliferous limestone with some soft shale
Abrigo limestone
700 feet
Thin-bedded impure cherty limestone with shaly and sandy layers
Bed of white quartzite about 5 feet thick at top
Bolsa quartzite
440 feet
Hard quartzite in beds up to 6 feet thick. Small scattered pebbles
Thin conglomerate at base
GREAT UNCONFORMITY
Pinal schist
and gneissic quartz mica diorite
140 miles
100 miles
90 miles
III
CLIFTON
After Lindgren W
U S Geological Survey
Folio 129
1905
Pinkard formation
Shale and sandstone of Benton age
UNCONFORMITY
Tule Spring limestone
500 feet
(Includes some Mississippian)
Thick bedded blue gray limestone
Modoc limestone
180 feet
Upper 100 feet pure thick bedded limestone lower 80 feet dolomitic in part with one bed of sandstone
Morenci formation
150 feet
Black clay shale grading down into argillaceous limestone
Longfellow formation
200-400 feet
Cherty limestone locally dolomitic. Lower 250 feet thinner-bedded with considerable shale. Ordovician fossils in upper division
ORDOVICIAN
Coronado quartzite
200 feet
Brown and red quartzitic sandstone with conglomerate locally at base
GREAT UNCONFORMITY
Pinal schist and granite
IV
GLOBE AND RAY QUADRANGLES
Ransome F L
Washington Academy of Sciences Journal
vol 5 pp 380-388
1915
Andesite andesite breccia and tuff
UNCONFORMITY
Tornado limestone
1000+ feet
Thick beds of light gray limestone. Fossils scarce in lower or Mississippian portion but plentiful in Pennsylvanian portion
No recognizable plane of division between Mississippian and Pennsylvanian
Martin limestone
325 feet
Generally rather thin beds
Fossiliferous in upper half
Gritty at base. Shale at top
Troy quartzite
400 feet
Generally pebbly cross bedded quartzite with lenses of conglomerate
Shaly rusty beds with worm casts at top
Vesicular basalt flow 25-75 feet
Mescal limestone
225 feet
Thin varicolored more or less dolomitic beds with conspicuous cherty layers
Dripping Spring quartzite
450 feet
Fine-grained varicolored arkosic quartzite much of it with dark red and gray banding. Partings between beds not distinct. Ripple marks
Barnes conglomerate
10-55 feet
Pioneer shale 150 feet
Maroon shale arkosic and quartzitic near base
Scanlan conglomerate 0-15 feet
GREAT UNCONFORMITY
Pinal schist
and intrusive granitic rocks
Apache group
25 miles
30 miles
15 miles
V
ROOSEVELT
Ransome F L
From unpublished data
Tornado limestone
Martin limestone
300± feet
Thin dolomitic beds with some sandstone and shale especially in upper part
Troy sandstone
160 feet
Cross bedded pebbly sandstone
Some shale near base
Vesicular basalt flow 30 feet
Mescal limestone
300 feet
Hard rather thin bedded cherty dolomitic limestone
Weathers dark
Dripping Spring quartzite
500± feet
Same general character as in Globe and Ray quadrangles
Barnes conglomerate
15-20 feet
Pioneer shale
255 feet
Maroon shale grading into massive hard arkosic sandstone below
Scanlan conglomerate 30 feet
Pebbles up to 8 inches
GREAT UNCONFORMITY
Granite
VI
SOUTHERN PART OF THE SIERRA ANCHA
Ransome F L
From unpublished data
Summit of Aztec Peak
Massive medium grained quartzitic sandstone 200± feet
Hard white quartzitic sandstone with streaks of pebbles
Beds 5-6 feet. Forms cliff
200 feet
Coarse pebbly pink to buff sandstone 75 feet
Massive fine grained gray to white sandstone. Forms slope 75 feet
Massive fine grained pink to buff sandstone. Forms cliff
Layers of pebbles
200 feet
Fine grained homogeneous pinkish sandstone. Weathers slabby and forms slope
300 feet
Fine-grained red brown flaggy sandstone 50 feet
Vesicular basalt flow 30± feet
Mescal limestone
(thickness unknown)
No good exposures seen
Probably about 250 feet
Dripping Spring quartzite
500± feet
Same general character as in Globe and Ray quadrangles and at Roosevelt
Barnes conglomerate
5-20 feet
Pioneer formation
200± feet
Red brown arkosic sandstone with some maroon shale
Scanlan conglomerate 6 feet
GREAT UNCONFORMITY
Granite
30 miles
VII
NORTHERN PART OF THE SIERRA ANCHA
DELSHAY BASIN
Ransome F L
From unpublished data
Crest of Sierra Ancha
Purplish brown calcareous shale and impure cherty limestone 125 feet
Exposures lacking. Fragments of sandstone chert impure limestone and shale 100 feet
Thin bedded rusty quartzitic sandstone 100 feet
Thin bedded flaggy sandstone with some shale. Weathers rusty
Slope 100 feet
Massive pink quartzitic sandstone. Forms cliff 75 feet
Pink quartzitic sandstone. Forms slope 25 feet
Massive pink quartzitic sandstone. Forms cliff 50 feet
Conglomerate 2 feet
Massive fine grained red brown sandstone. Beds 12 feet or more thick. Cross bedded at low angles. Forms cliff
150 feet
Apparently fine grained red-brown sandstone. Exposures poor
Coarse red brown arkosic quartzitic sandstone with layers of conglomerate and of spotted red shale 150 feet
Conglomerate 3 feet
GREAT UNCONFORMITY
Granite
(The above section elsewhere overlies unconformably older Cambrian schist and younger pre Cambrian quartzite and conglomerate)
35 miles
VIII
HEAD OF CANYON CREEK
Gilbert G K
Wheeler Survey
Vol 3 pp 163 164
1875
Erosion surface
Coconino sandstone
525 feet
Massive cross-bedded yellow sandstone
Compact gray limestone 65 feet
Red and purple sandstone soft at top massive below
500 feet
Supai formation (?)
Redwall limestone ?
325 feet
Alternating gray limestone and shale with some sandstone
Fossiliferous
UNCONFORMITY ?
Brown to red coarse vitreous sandstone. Massive to shaly 100 feet
Gray sandstone weathering red 75 feet
Shaly calcareous sandstone 75 feet
Vitreous red purple and white sandstone 150 feet
Coarse siliceous conglomerate 25 feet
GREAT UNCONFORMITY
Hornblende rock and schists
Tonto group
75 miles
75 miles
IX
JEROME REGION
Ransome F L
From unpublished data
Erosion surface
Coconino sandstone
500± feet
Fine grained thick bedded sparkling buff to white sand stone with conspicuous cross bedding
Supai formation ?
1000± feet
Soft calcareous shales and sandstones with some sandy limestone
General color bright red
Thick bed of gray limestone at top
Redwall limestone ?
250 feet
Thick bedded white and gray limestone
Thin bedded compact lime stone in lower part becoming sandy in upper part
Devonian fossils
500 feet
DEVONIAN at least in part
Rusty cross bedded pebbly sandstone 80 feet
GREAT UNCONFORMITY
Schist
100 miles
X
GRAND CANYON
KAIBAB DIVISION
Based chiefly on work of L F Noble
U S Geological Survey
Bulletin 549 Plate IX
1914
Erosion surface
Kaibab limestone
400-600 feet
Upper portion dense gray crystalline limestone cherty near top
Fossiliferous
Lower portion buff limestone and calcareous sandstone
Coconino sandstone
250-350 feet
Light-buff fine-grained calcareous sandstone with conspicuous cross bedding
Supai formation
1250-1400 feet
Upper portion soft red shaly sandstone and red shale
Lower portion hard fine-grained cross bedded sand stone interbedded with red shale
Redwall limestone
600-700 feet
Alternating beds of calcareous sandstone thin bedded mottled limestone and dense blue gray limestone in lower portion pass ing upward into dense blue gray limestone with bedding planes indistinct
UNCONFORMITY
Temple Butte limestone
0-100 feet
UNCONFORMITY
Muav limestone
450-475 feet
Impure thin-bedded bluish-gray limestone with characteristic mottling due to lenses of shaly material
Bright Angel shale
25-375 feet
Soft greenish micaceous sandy shale with two thin beds of brown limestone locally present in middle
Fossiliferous
Tapeats sandstone
0-285 feet
Brown slabby cross-bedded sandstone with lense of conglomerate in basal portion
Tonto group
GREAT UNCONFORMITY
PRE-CAMBRIAN
Grand Canyon series younger pre Cambrian including over 4700 feet of conglomerate limestone shale quartzite and sand tone resting unconformably on schist and granite of older pre Cambrian
INDEX MAP SHOWING LOCATION OF SECTIONS MEASURED AND RELATION OF LOCALITIES VISITED TO PUBLISHED TOPOGRAPHIC AND GEOLOGIC WORK IN ARIZONA
Outlined rectangles represent topographic maps. Shaded areas represent published geologic folios
Dots and roman numerals represent locations of columnar sections
GULF OF CALIFORNIA
MOUNT TRUMBULL
KAIBAB
ECHO CLIFFS
MARSH PASS
CANYON DE CHELLY
CAMP MOHAVE
CHINO
SAN FRANCISCO MTN
APACHE
FORT DEFIANCE
NAVAJO
TUSAYAN
DIAMOND CREEK
COCONINO
Flagstaff
Holbrook
HOLBROOK
ST JOHNS
Prescott
VERDE
YAVAPAI
Wickenburg
PHOENIX
YUMA
Yuma
Gila River
PINAL
Florence
GRAHAM
PIMA
Tucson
COCHISE
Nogales
Bisbee
Tombstone
Douglas
Fort Grant
Maricopa
Needles
Clifton
Seymour

BARNES CONGLOMERATE.

The Barnes conglomerate lies stratigraphically above the Pioneer shale and below the Dripping Spring quartzite. The formation was first described in the Globe report and was named from Barnes Peak, in the northwestern part of the Globe quadrangle, where it is from 10 to 15 feet thick. There is no apparent unconformity either above or below the conglomerate, although the abrupt change from a fine shale to a deposit of coarse pebbles is indicative of so extensive a modification of the conditions of erosion and sedimentation under which the shales accumulated as would seem to demand a notable unconformity of contemporaneous origin somewhere within the region of deposition.

In its typical development, as near Pioneer Mountain or on Silver Creek, in the Ray quadrangle, the Barnes conglomerate consists of smooth pebbles of white quartz and hard vitreous quartzite in an arkosic matrix. The pebbles are generally 6 inches or less in diameter but in a few places there are some as much as 8 inches in diameter. Although smoothly rounded, the pebbles are not globular but are flattened ellipsoids or round-edged disks. They are composed only of the most durable materials and doubtless passed through long and varied processes of attrition before they came to rest in the Barnes conglomerate. On the whole, such meager evidence as is obtainable appears to indicate that the conglomerate represents stream action rather than littoral or marine action. The formations that supplied the quartzitic material to the conglomerate, as will be shown later, are exposed north of Roosevelt, in the Sierra Ancha and the Mazatzal Range.

In some places the pebbles, which generally lie with their flat sides roughly parallel to the bedding planes, are in contact and the proportion of arkosic matrix is correspondingly small; in other places the matrix predominates. As a rule, the pebbles become larger and more abundant toward the south, although the gradation is probably not wholly regular. Thus at Barnes Peak the average diameter of the pebbles is 3 or 4 inches and the thickness of the formation from 10 to 15 feet. In the vicinity of El Capitan Mountain, in the Mescal Range, pebbles 6 inches in diameter are abundant, the average size is probably a little larger than at Barnes Peak, and the thickness of the formation is from 15 to 20 feet. At the north end of the Dripping Spring Range the conglomerate is rather variable. A small exposure about 1⅓ miles north of Walnut Spring shows thin bands of pebbles associated with pinkish arkose and gray shale. The pebbles, which are chiefly white quartz and not very well rounded, rarely exceed 2 inches in diameter and not any over 3 inches were seen. About 2 miles northwest of Walnut Spring the whole formation is from 10 to 12 feet thick, but the arkosic matrix is much more abundant than the pebbles, which although not uniformly distributed are, as a rule, most numerous near the base. The lower part of the bed thus presents in some places the aspect of the typical Barnes conglomerate, but the upper part is distinguishable from the overlying quartzite only by the occurrence within it of a few small and scattered pebbles.

Northeast of Tam O'Shanter Peak, on the other hand, the conglomerate is about 40 feet thick and consists of chiefly smooth, rounded pebbles that are generally in contact with one another, with just enough matrix to fill the interstices. Some of the pebbles are as much as 10 inches in diameter, but most of them are under 6 inches. In the Tortilla Range, south of Kelvin, the conglomerate is about 55 feet thick and contains abundant characteristic pebbles 8 inches or less in diameter.

The arkosic matrix of the conglomerate is generally similar to the material of the overlying Dripping Spring quartzite, although perhaps a little coarser. It varies in hardness, but as a rule all the constituents of the conglomerate are cemented by silica into a hard and durable rock in which fractures traverse pebbles and matrix alike. A very characteristic feature of the Barnes conglomerate is the presence in the matrix of small fragments of vermilion-red chert or jasper as much as an inch or so in diameter.

A view of the upper part of the Barnes conglomerate as exposed on El Capitan Creek, in the northeastern part of the Ray quadrangle, is shown in Plate XXVI, *C*.

DRIPPING SPRING QUARTZITE.

The Dripping Spring quartzite lies conformably on the Barnes conglomerate and under the

Mescal limestone.[1] Approximately the lower third of the formation consists of hard fine-grained arkosic quartzites, which, as seen in natural sections, show no very definite division into distinct beds but do exhibit a pronounced striping, due to the alternation of dull-red and dark-gray or nearly black bands parallel with the planes of stratification. These bands as a rule are less than 1 foot thick and give a generally thin-bedded aspect to this portion of the formation, as may be seen from Plate XXVII, *B*, although the illustration fails to show the contrasting tints of the bands. About midway between the top and bottom of the formation the striped beds are succeeded by fairly massive beds, as much as 6 feet thick, of even-grained buff or pinkish quartzite associated with flaggy variegated red, brown, and gray beds and with some layers of gray and reddish shales suggestive of the Pioneer shale.

In the upper part of the formation the beds become thin, flaggy, and rusty, with a tendency to grade into the Mescal limestone.

The sand which became the Dripping Spring quartzite was deposited in shallow water and was at times exposed to the air, as may be seen from the ripple marks, sun cracks, and fossil worm casts visible on the surface of the beds. The deposit is tentatively regarded as of delta origin. It is composed throughout of fine material, and contains no pebbles, so far as known. This feature and the banding of its lower beds serve throughout the Ray quadrangle to distinguish this quartzite from the pebbly cross-bedded Troy quartzite, to be described later.

Where almost vertically upturned in the Tortilla Range the Dripping Spring quartzite appears to be about 500 feet thick, but the presence of intrusive diabase detracts a little from the reliability of this measurement, as movements during the intrusion may have increased the apparent thickness. Southwest of Pioneer Mountain, where the whole of the quartzite seems to be exposed without noticeable faulting, the thickness obtained by calculation from the width of the outcrop as mapped, the average dip of the beds, and the general angle of topographic slope is between 450 and 500 feet. At Barnes Peak, in the Globe quadrangle, the thickness was estimated at 400 feet. The average thickness for the Ray quadrangle is taken at 450 feet, which is probably under rather than above the truth.

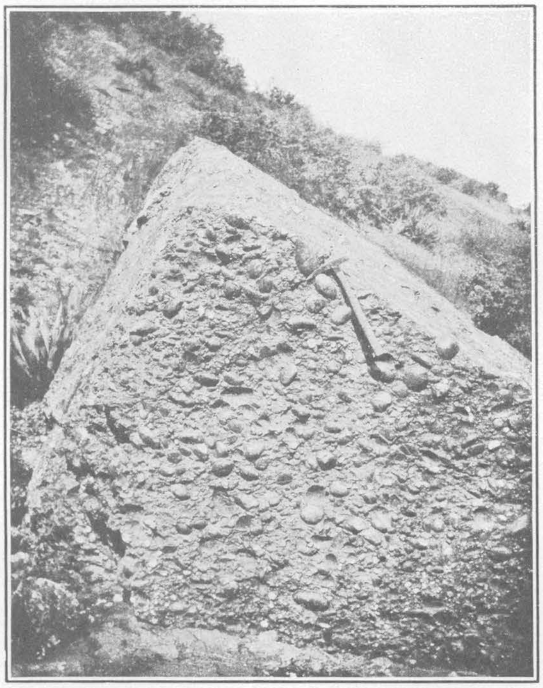
[1] This is a redefinition of Dripping Spring quartzite as the name was originally used in the Globe quadrangle. The reasons for the change have been published (Min. and Sci. Press, vol. 102, pp. 747-748, 1911) and are summarized on pages 143-144 of the present paper.

MESCAL LIMESTONE.

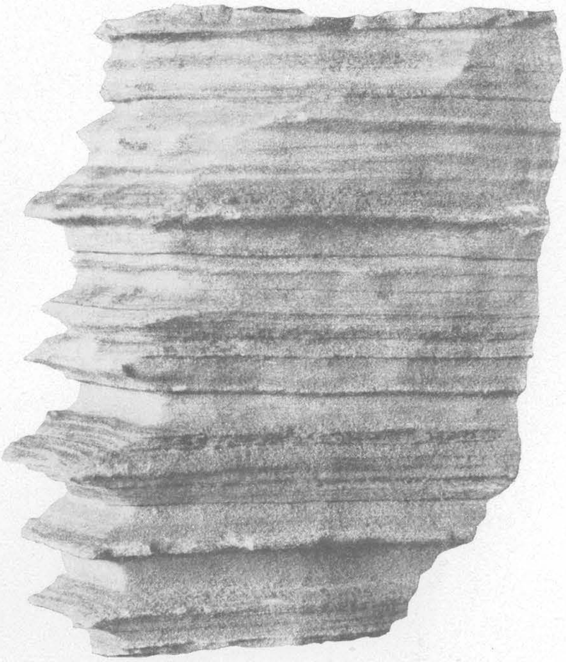
The Mescal limestone was first recognized as a distinct formation in the course of mapping the Ray quadrangle and is named from the Mescal Mountains, where it is well exposed. Stratigraphically it is limited below by the Dripping Spring quartzite and above by the Troy quartzite. Some fragments of this formation, most of them intimately associated with intrusive diabase, occur in the Globe quadrangle, but when the report on that area was prepared these masses of strata were supposed to be somewhat metamorphosed portions of the thin Devonian beds in the lower part of the "Globe limestone."

In the Ray quadrangle also the Mescal limestone and the diabase are closely associated. Lying between the two heavy quartzitic formations, the thin-bedded dolomitic limestone proved an easy path for the invading diabase magma and retains little of its former continuity. In the development of the topography the diabase tends to wear down into swales and hollows, and an extended view over one of these depressions shows the generally olive-tinted surface characteristic of diabase areas, varied by blotches of white that represent included blocks of the Mescal limestone, some of which are nearly a quarter of a square mile in area. Other portions of the formation rest in their original position on the Dripping Spring quartzite, and the diabase lies in igneous contact above them. Still others crop out along the bases of cliffs formed by the Troy quartzite and lie above the intruded diabase. Rarely the limestone lies unbroken between the two quartzites.

The Mescal limestone is composed of thin beds that have a varied range of color, but are persistently cherty, the siliceous segregations as a rule forming irregular layers parallel with the bedding planes. On weathered surfaces these layers stand out in relief and give to the limestone the rough, gnarled banding that is its most characteristic feature. The usual appearance of the Mescal limestone on outcrop-

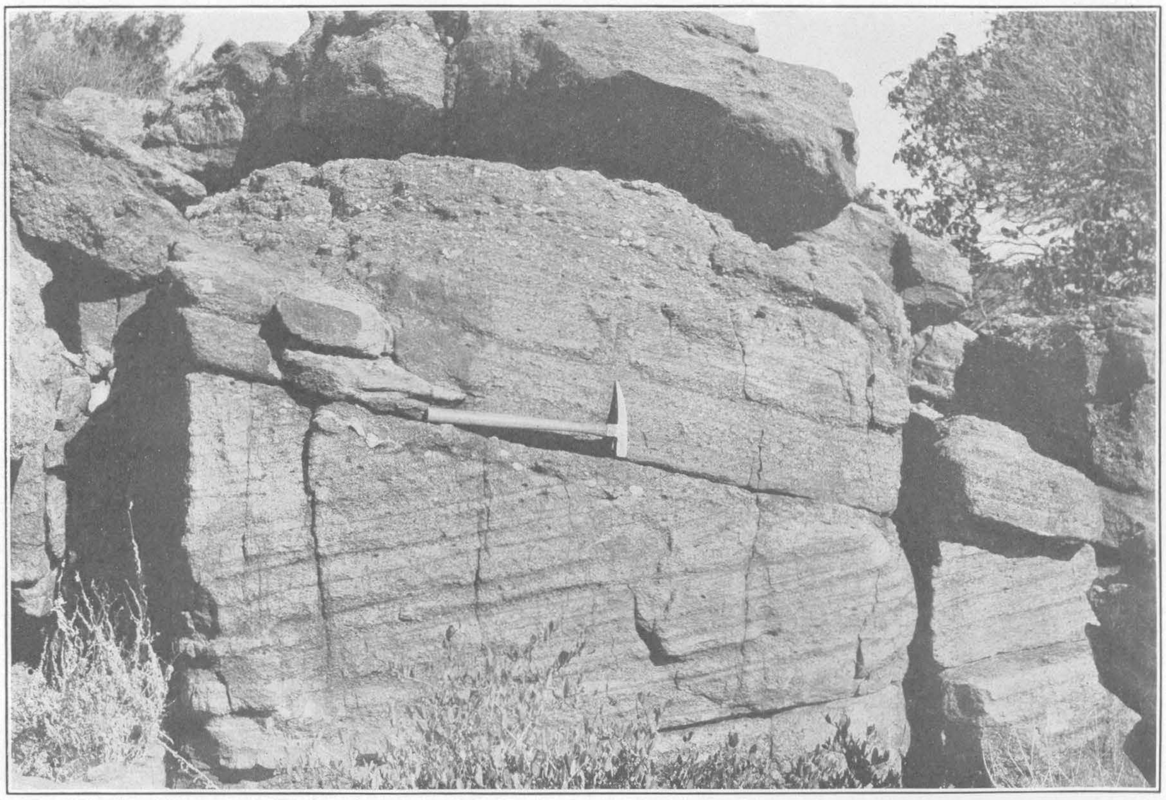


A. BARNES CONGLOMERATE AT SOUTH END OF PINAL RANGE, GLOBE QUADRANGLE, ARIZ.



B. MESCAL LIMESTONE ON EL CAPITAN CREEK, MESCAL RANGE, RAY QUADRANGLE, ARIZ., SHOWING EFFECT OF WEATHERING.

C. BARNES CONGLOMERATE, EL CAPITAN CREEK, ARIZ.



A. CROSS-BEDDED PEBBLY TROY QUARTZITE, DRIPPING SPRING RANGE.

B. BANDED DRIPPING SPRING QUARTZITE, MESCAL RANGE, 1 MILE SOUTH OF PIONEER.

QUARTZITES OF THE RAY QUADRANGLE, ARIZ.

ping edges is shown in Plate XXVIII. The general hue of the formation is gray or white, but some beds are yellow, buff, brown, or rusty. In some localities the rough, gnarled strata are accompanied by others containing thin regular buff and gray layers whose differences in chemical composition in conjunction with the dissolving action of atmospheric water gives rise to such natural ornamentation as is illustrated in Plate XXVI, *B*.

Between the limestone and the overlying Troy quartzite is a layer of decomposed vesicular basalt whose maximum observed thickness is 100 feet. Although the basalt is in places much thinner than this, the flow was apparently coextensive with the Mescal limestone throughout the Ray and Globe quadrangles. Where the basalt is in contact with the later intrusive diabase distinction between the two is difficult in the absence of good exposures, and in the earlier work in the Globe quadrangle the altered vesicular basalt was supposed to be merely a contact modification of the diabase.

A section of the Mescal limestone with the overlying basalt flow, as exposed on the east side of El Capitan Canyon, is given below. The thicknesses stated are approximate.

Section of the Mescal limestone.

	Feet.
Troy quartzite.	
Vesicular basalt	75
4. Striped buff and gray dolomitic limestone weathering sharp channels and ridges, as illustrated in Plate XXVI, *B*	15
3. Very rough cherry dolomitic limestone with no distinct division into beds. Weathers with gnarly dark rusty-brown surface	30
2. Gnarled, knotty cherty limestone, mostly dolomitic, in beds as much as 2 feet thick. Some beds light gray and some dark brown. Shaly partings	125
1. Thin impure shaly limestone, with perhaps some dolomite. Splits into thin leaves. Mostly light gray	50
Dripping Spring quartzite.	
	295

The analysis of a sample from division 2 of the foregoing section is as follows:

Partial chemical analysis of Mescal limestone.

[George Steiger, analyst.]

SiO_2	29.93
Al_2O_3	.42
CaO	21.90
MgO	14.90

This rock weathers brown but on fresh fracture is almost white. The molecular ratio of lime and magnesia is nearly that of dolomite, but as the beds are not all of the same character the foregoing analysis does not represent accurately the composition of the whole formation.

In the narrow gorge just west of Hackberry Spring, in the southwestern part of the Ray quadrangle, the Mescal limestone stands almost vertical and has a thickness of 225 feet. In the section given above the total thickness is stated as 220 feet, exclusive of the vesicular basalt. This, however, is an estimate based on barometric readings corrected for a dip of about 25°. The average thickness of the formation as mapped in the Ray quadrangle and including the basalt flow may be taken as about 250 feet.

TROY QUARTZITE.

The Troy quartzite lies conformably above the Mescal limestone and below the Martin limestone. Prior to the detailed mapping of the Ray quadrangle this quartzite had not been recognized as a formation distinct from the lower or Dripping Spring quartzite, for in the Globe quadrangle there are no sections that show the two quartzites separated by the intervening Mescal limestones, and such brief papers on the geology of the Ray quadrangle as have appeared since the Globe report was published have dealt only with the immediate surroundings of the copper deposits at Ray, where the stratigraphic relations of the sedimentary rocks are less clearly displayed than elsewhere in the quadrangle. The name of the formation is derived from Troy Mountain, in the Dripping Spring Range.

The Troy quartzite is one of the most prominent and widely exposed formations in the Ray quadrangle. The beds differ greatly in thickness, ranging from thin flaggy or shaly layers to cross-bedded pebbly beds from 25 to 50 feet thick. On the whole the thicker beds are characteristic of the lower and middle portions of the formation. The upper part is invariably composed of thin, generally yellowish or rusty worm-marked shaly quartzite indicative of a change in sedimentation preparatory to the deposition of the Devonian limestone. The most characteristic material of these upper beds consists of layers, an inch or two thick, of fine-grained, unevenly colored brown, pink, and green quartzite separated by films of olive-gray shale whose cleavage surfaces are ridged and knotted with numerous worm casts. The quartzite layers appear almost dolomitic in color and texture, but the microscope shows them to consist chiefly of closely fitting quartz grains with specks of flocculent limonite and little nests of a green chloritic mica. The most noteworthy features of the thicker beds are their generally pebbly character, which is a useful means of distinguishing isolated exposures of the Troy quartzite from the pebble-free Dripping Spring quartzite, and their conspicuous cross-bedding. These characteristics are illustrated in Plate XXVII, *A*. While the Dripping Spring quartzite is nearly all arkosic the Troy quartzite shows little or no feldspar.

A not quite complete section of the Troy quartzite as exposed in nearly horizontal attitude 1½ miles southeast of Tam O'Shanter Peak, in the Dripping Spring Range, is given below, with approximate thicknesses.

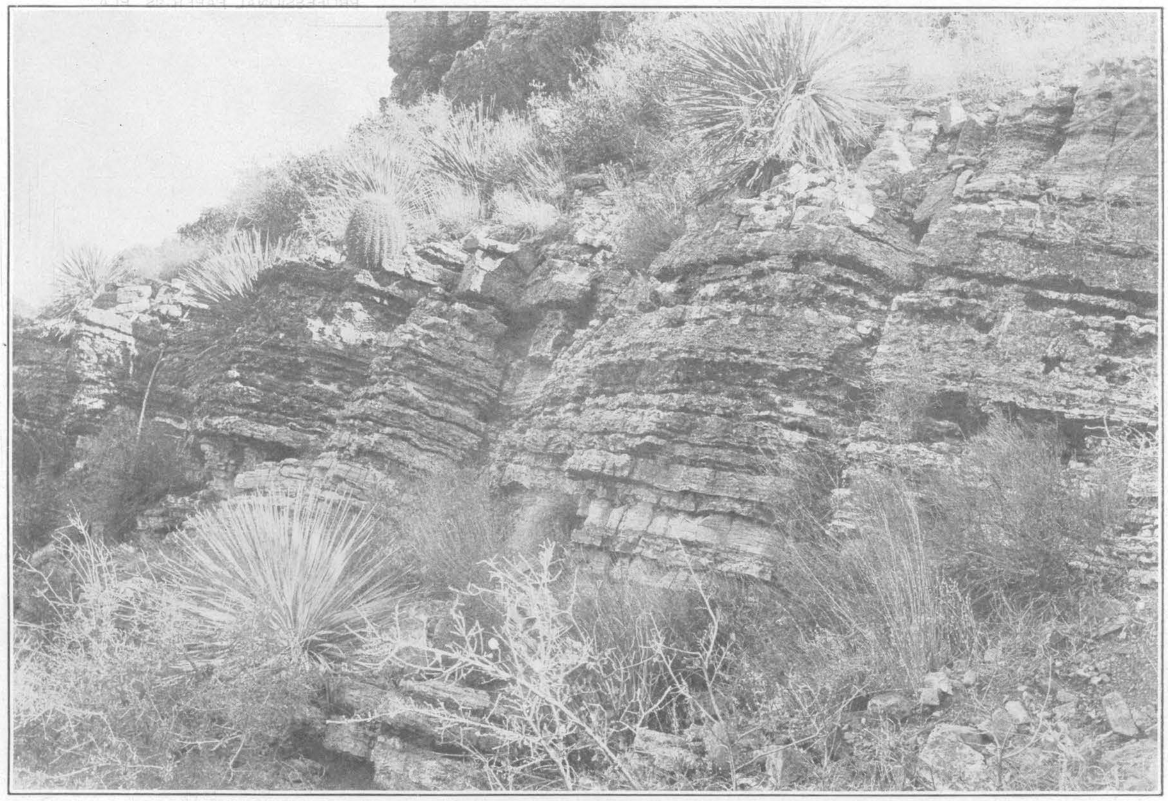
Section of Troy quartzite.

		Feet.
11.	Yellowish, rusty, thin-bedded quartzites with olive-gray shale partings roughened by worm casts; at least	50
10.	Fine-grained quartzite with very regular laminations from 2 to 6 inches thick	1½
9.	Rather thin beds of white fine-pebbly quartzite	50
8.	A single bed of massive cross-bedded fine-pebbly white quartzite, with layers of small quartz pebbles every few feet. Forms a cliff	50
	Sheet of porphyry, 25 feet.	
7.	Partly concealed; apparently rather thin bedded gray pebbly quartzite	35
6.	Two beds of cross-bedded coarse quartzite or grit, with scattered pebbles of white quartz as much as 6 inches in diameter. Forms a scarp	15
5.	Conspicuously cross-bedded gray quartzite, with many layers of small quartz pebbles. No distinct separation into beds, but obscure laminations average about 1 foot in thickness. Forms a stepped slope. Microscope shows typical quartzite texture with enlarged interlocking quartz grains	75
4.	Conglomerate with fairly well rounded pebbles, mostly of white quartz, as much as 4 inches in diameter, in an abundant cross-bedded matrix of coarse quartzite	6
3.	Soil-covered slope, apparently underlain by a yellowish shale or fine-grained quartzite	25
2.	Cross-bedded pebbly quartzite in beds 4 to 10 feet thick. Pebbles quartz; rarely over 2 inches in diameter; in places scattered and in places concentrated in irregular lenticular layers. Weathers gray or rusty. Forms a stepped slope	25
1.	Bed of irregularly banded gray quartzitic breccia grading up into cross-bedded coarse grit or conglomerate with quartz pebbles. Breccia in lower part of bed contains angular fragments of white quartz 6 inches or less in diameter. Forms a cliff	30
		362½

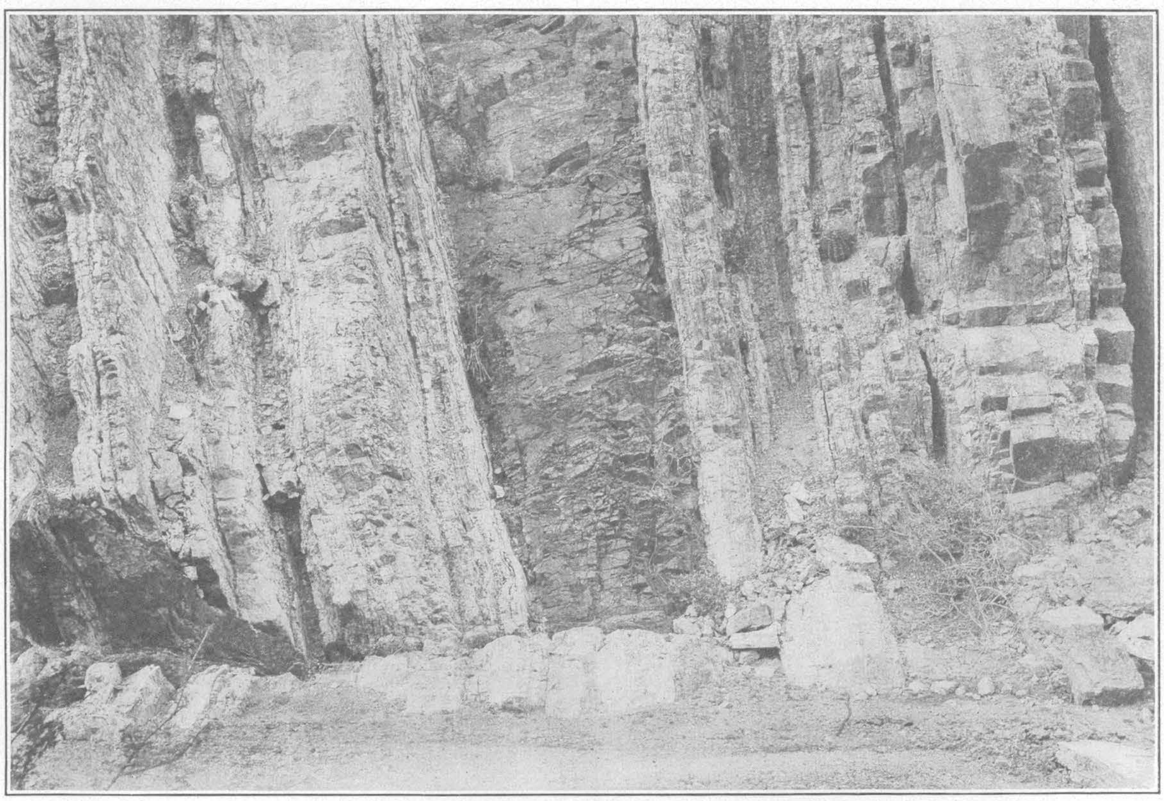
Bed No. 1 is the bottom of the Troy quartzite. Below it is the vesicular basalt at the top of the Mescal limestone.

Although much of the Troy quartzite is light gray or white on fresh fracture, the weathered exposures are generally buff, brown, rusty, or maroon. In the canyon northwest of Tam O'Shanter Peak, where the quartzite is finely exposed, the general tint is reddish brown, but the different parts of the formation vary in color from white or pale buff to dull dark red.

Determination of the exact thickness of the Troy quartzite is difficult, owing to the fact that few of the many fault blocks show a full section of the formation or give opportunity for detailed measurements. The section recorded above gives a total thickness of about 362½ feet but probably does not include all the upper beds. In the gorge west of Hackberry Spring a measurement across the edges of the nearly vertical beds gave 300 feet, but here also there are beds missing from the top of the formation. A little less than 2 miles northwest of Tam O'Shanter Peak the formation, here nearly horizontal, is exposed in full section between the Mescal dolomite and the Devonian limestone. The mapping here indicates a thickness of a little more than 350 feet. On Troy and Scott mountains the quartzite as mapped appears to be unduly thick, the distribution on Scott Mountain calling for a thickness of about 1,000 feet. This is clearly in excess of any possible real increase in the formation and probably is to be accounted for by faulting or flexing that is not distinctly shown at the surface. From all available information the average thickness of the formation is estimated to be about 400 feet.

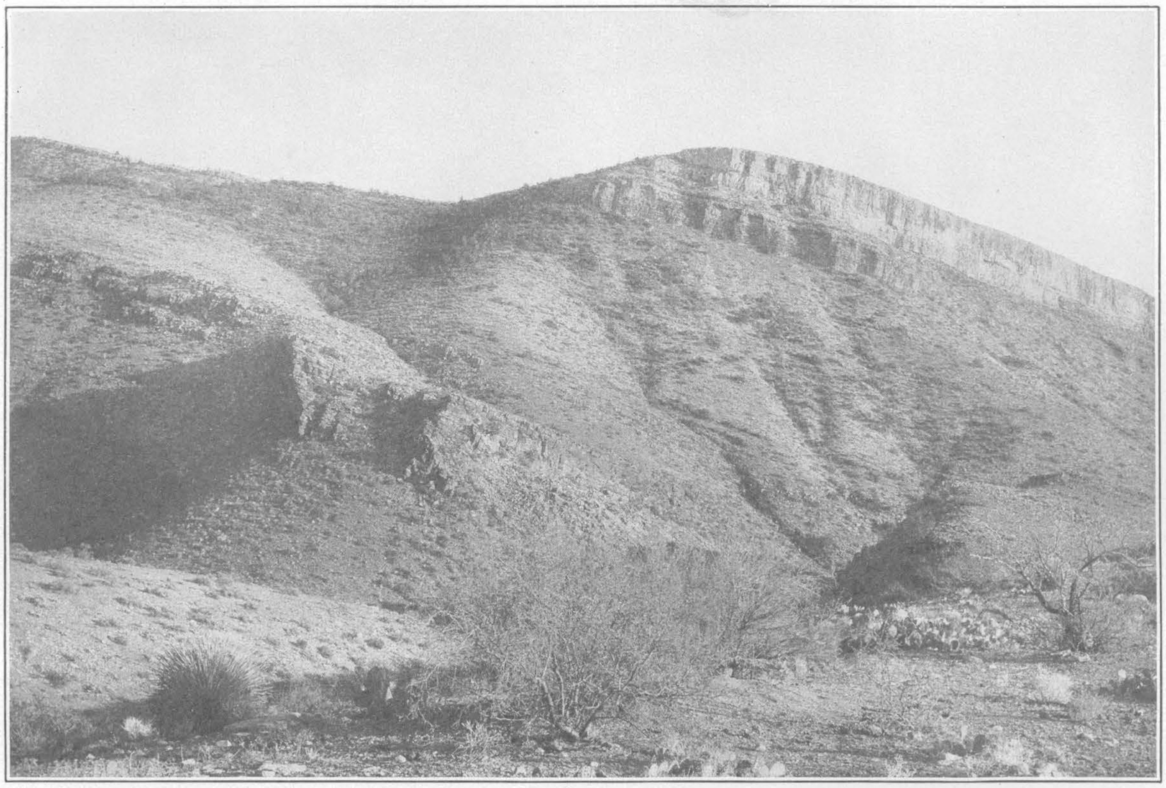


A. TYPICAL EXPOSURE OF THE CHERTY MESCAL LIMESTONE IN THE DRIPPING SPRING RANGE, 2 MILES SOUTH OF DRIPPING SPRING RANCH.

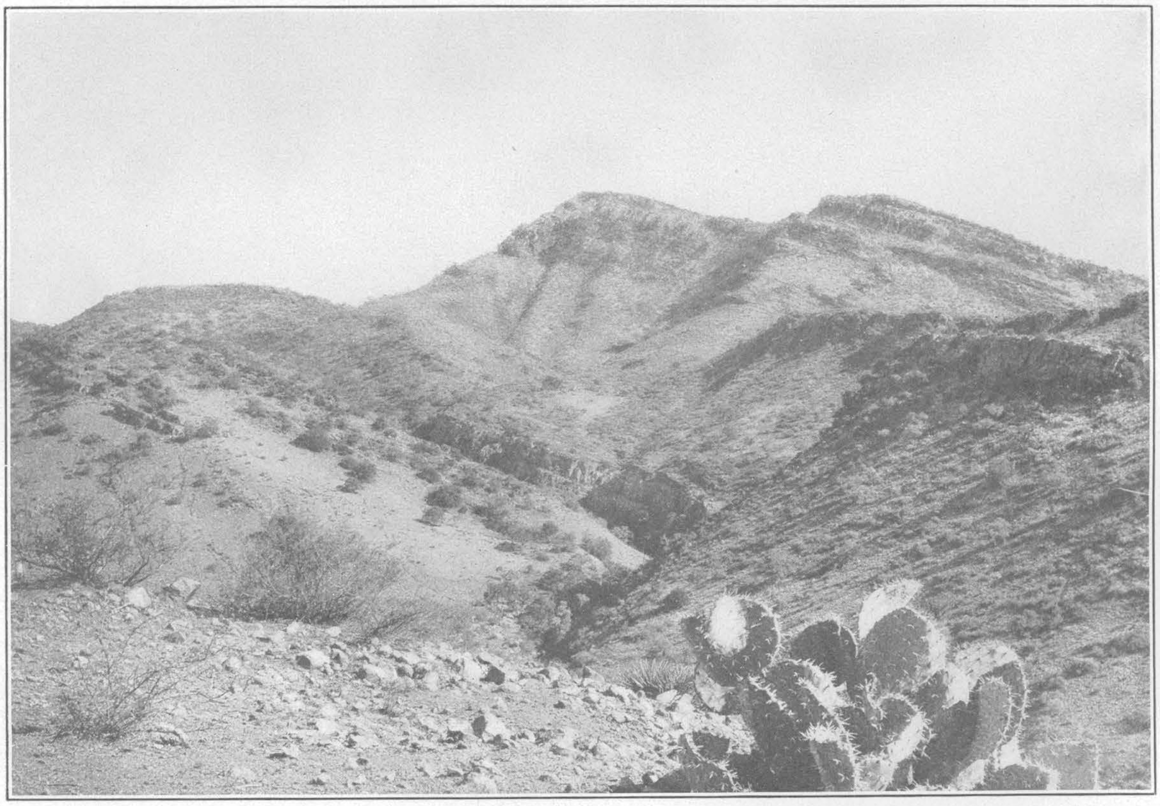


B. STEEPLY UPTURNED MESCAL LIMESTONE WITH INTRUSIVE DIABASE IN THE TORTILLA RANGE, ABOUT 6 MILES SOUTH OF KELVIN.

MESCAL LIMESTONE IN THE RAY QUADRANGLE, ARIZ.



A. SECTION ON EL CAPITAN CREEK, MESCAL RANGE.



B. EL CAPITAN FROM THE NORTHWEST.

SECTIONS OF PALEOZOIC ROCKS IN THE RAY QUADRANGLE, ARIZ.

The Troy quartzite, with its abundant pebbly layers and conspicuous cross-bedding, is suggestive of fluviatile or deltaic deposition. The upper part of this formation, however, grades into the undoubtedly marine Devonian beds.

MARTIN LIMESTONE.

The Martin limestone occupies conformably the stratigraphic interval between the underlying Troy quartzite and the overlying Tornado limestone and, with the possible exception of some of its unfossiliferous lower beds, is of Devonian age. The beds here separated as the Martin limestone were in the Globe quadrangle mapped with the overlying Carboniferous (Tornado) limestone under the name "Globe limestone."

As a whole the Martin limestone is a comparatively thin bedded formation, which weathers into slopes broken here and there by low scarps marking the outcrop of some bed a little harder or thicker than the rest. A typical natural section of the formation is shown in Plate XXIX, *A*. Distant views of such slopes show that the formation is divisible on the basis of color into two nearly equal parts. The prevailing hue of the lower division is light yellowish gray; the upper division, less uniform in tint, displays alternations of deeper yellow and darker gray. Detailed examination proves the lower division to consist mainly of very compact, hard, gray limestone in beds rarely more than 2 feet thick, with, at the base, a bed of impure yellow limestone containing abundant grains of quartz. This lowest bed, which in places is cross-bedded and contains so much detrital material that it might be classed as a calcareous grit, weathers to a rough sandy surface, but the overlying gray beds are characterized by solution surfaces that although uneven in general are smooth in detail. A characteristic feature of these compact lower limestones is the presence of little spherical, oval, or irregular concretions of dark chert, which as a rule are about the size of peas. No identifiable fossils have been found in this lower division of the Martin limestone, although it contains obscure traces of organic life.

About midway in the section is a bed, about 15 feet thick, of rusty-yellow impure sandy limestone showing flaggy lamination. Above this are dark-gray and yellowish limestones in beds of different thicknesses, with shaly partings. These strata are generally fossiliferous, some of the shaly partings particularly being crowded with *Atrypa reticularis* and other small Devonian brachiopods. Some very dark beds in this upper division of the formation are marked with an obscure mottling suggestive of the former presence of some of the corals which are abundant in certain beds of the Martin limestone at Bisbee but which in the Ray quadrangle have been less perfectly preserved. The top bed of the Devonian is a yellow calcareous shale which breaks up on exposure into minute thin flakes and which consequently has no prominent outcrops. The yellow color is characteristic of all natural exposures, although before weathering the shale is gray. Being overlain by the massive cliff-making Carboniferous limestone, the bed of shale is in many places concealed by talus, and its thickness was not exactly determined. It may be from 15 to 20 feet thick, but its base is not very clearly defined, for layers of similar shale occur between some of the limestone beds in the upper part of the formation.

The Devonian limestone is generally magnesian and does not effervesce freely in cold dilute acid. An analysis of a typical specimen from the lower division of the formation is as follows:

Partial chemical analysis of Devonian limestone.

[R. C. Wells, analyst.]

SiO_2	3.11
Al_2O_3	.33
Fe_2O_3 and FeO	1.22
CaO	31.65
MgO	18.65

Measurements and estimates of the thickness of the Martin limestone in different parts of the quadrangle range from 300 to 350 feet. The average thickness is considered to be 325 feet.

In contrast with the older formations, which have yielded no determinable organic remains, the upper division of the Martin limestone contains fossils at many horizons from the top of the rusty bed at its base to the lower layers of the yellow shale. In all 18 lots of fossils were collected and were referred to E. M. Kindle, then of the United States Geological Survey, who lists the following species:

- Zaphrentis sp. undet.
- Productella hallana.
- Stropheodonta arcuata.
- Stropheodonta demissa.
- Stropheodonta varistriata.
- Stropheodonta sp.
- Leptostrophia cf. L. interstrialis.
- Strophonella cf. S. ampla.
- Schuchertella chemungensis.
- Schizophoria striatula.
- Atrypa reticularis.
- Atrypa hystrix occidentalis.
- Atrypa spinosa.
- Camarotœchia sp.
- Pugnax pugnus.
- Spirifer orestes.
- Spirifer hungerfordi.
- Cyrtia cyrtiniformis.
- Schizodus sp.
- Paracyclas cf. P. elliptica.
- Euomphalus cyclostomus?
- Euomphalus sp.
- Bellerophon sp. undet.

Dr. Kindle remarks with reference to this fauna:

> On the ground of its close relationship to an Upper Devonian fauna of Iowa and its stratigraphic relations to the Carboniferous fauna of the Arizona section, I would place the fauna of the Martin limestone and its equivalent, the Devonian fauna of the Ray quadrangle, in the Upper Devonian. It is of course possible that the time range of this fauna in Arizona may include Middle as well as Upper Devonian, but that it includes the Upper Devonian in any event seems well established by the available evidence.

As the Devonian portion of the "Globe limestone" in the Globe quadrangle is continuous and identical with what is now designated the Martin limestone, fossils collected from it should be included in the Martin fauna. For convenience therefore the list of determinations made by H. S. Williams [1] on the older collections, with slight changes by Dr. Kindle, to bring it into accord with present nomenclature, is given below.

- Cf. sponge.
- Cf. Rhodocrinus, crinoid stems and plates.
- Atrypa reticularis Linné.
- Productella hallana Walcott.
- Stropheodonta calvini Miller.
- Cyrtia cyrtiniformis (Hall and Whitfield).
- Spirifer hungerfordi Hall.
- Spirifer orestes Hall and Whitfield.
- Spirifer whitneyi Hall.
- Reticularia fimbriata (Conrad).
- Cyrtina hamiltonensis Hall.
- Martinia subumbona (Hall); cf. Spirifer infima Whidborne.
- Pugnax pugnus (Martin).
- Schuchertella chemungensis (Conrad) var.
- Dielasma cf. D. calvini (Hall and Whitfield).

[1] Ransome, F. L., U. S. Geol. Survey Prof. Paper 12, pp. 40-42, 1903.

TORNADO LIMESTONE.

The Tornado limestone, named from Tornado Peak, in the southeastern part of the Ray quadrangle, where it is extensively exposed, overlies with apparent conformity the Martin limestone and is equivalent to the Carboniferous portion of the "Globe limestone" as mapped in the Globe quadrangle. In places its upper limit is a surface of erosion upon which in general rests the Quaternary Gila conglomerate, although in the southeastern part of the Ray quadrangle there is an intervening andesitic formation, probably of Mesozoic age.

The Tornado limestone is generally light lead-gray in color and is divisible with respect to thickness and character of bedding into at least three members. The basal division, directly overlying the Devonian, is about 75 feet thick and forms the lower part of the scarp that is so prevalent a feature of the Carboniferous outcrops in central and southern Arizona. Under the action of erosion this division behaves as a single massive bed, but in reality it is made up of alternating dark and light gray layers, a foot or two thick which in cliff faces give this member a banded appearance, as may be seen in Plate XXIX, *A* (p. 141). This banded division with a few transitional beds at its top is succeeded by a very massive member, fully 100 feet thick, within which, as exposed in cliff faces, there is as a rule little more than a suggestion of divisional bedding planes. This massive member (Pl. XXIX, *A*) is of lighter and more uniform tint than the basal member. The two together constitute the principal cliff-forming part of the Carboniferous limestone. The third division consists of beds generally thinner than those in the other two divisions but not separable from them by any marked lithologic distinction.

The Tornado limestone consists essentially of calcium carbonate and effervesces freely in dilute acid. An analysis of a typical sample is as follows:

Partial chemical analysis of Tornado limestone.

[W. T. Schaller, analyst.]

SiO_2	1.36
Al_2O_3	.22
CaO	54.91
MgO	.21

Thin layers of calcareous shale separate some of the beds, but these are a very subordinate part of the formation.

Although nearly all the Carboniferous limestone contains fossil remains, there are few localities where full and satisfactory collections can be made. The beds of the two lower divisions carry abundant fragments of crinoid stems and less numerous rugose corals with long-winged spirifers and Rhipidomella. These appear in silicified form on weathered surfaces of the rock, but they can not readily be separated from their matrix. In the upper division appear different species of Productus and Spirifer, *Derbya crassa, Composita subtilita,* and Fusulina.

Of seven collections made at as many different localities in the Ray quadrangle, four, according to George H. Girty, of the Geological Survey, consist of Mississippian forms, and three of Pennsylvanian forms. His determinations of these fossils are as follows:

Mississippian fauna.

Syringopora aculeata Girty?
Menophyllum sp.
Amplexus? sp.
Rhipidomella aff. R. oweni Hall and Clarke.
Rhipidomella dubia Hall?
Leptæna analoga Phillips.
Schuchertella inflata White and Whitfield?
Chonetes sp.
Avonia arcuata Hall?
Camarotœchia metallica White.
Dielasma burlingtonense White.
Spirifer centronatus Winchell.
Brachythyris peculiaris Shumard.
Spiriferina solidirostris White.
Syringothyris sp.
Composita humilis Girty?
Cliothyridina sp.

Pennsylvanian fauna.

Fusulina sp.
Derbya crassa Meek and Hayden.
Productus semireticulatus Martin.
Productus cora D'Orbigny.
Pustula semipunctata Stevens.
Spirifer cameratus Morton.
Spirifer boonensis Swallow?
Composita subtilita Hall.
Myalina subquadrata Shumard.

According to Mr. Girty, the older of these two faunas is early Mississippian and the other is early Pennsylvanian. He notes that the conditions exhibited in the Ray quadrangle are apparently similar to those at Bisbee, where a limestone of probable early Pennsylvanian age (the Naco) rests directly on a limestone of early Mississippian age (the Escabrosa). The Mississippian in the Ray quadrangle, therefore, corresponds to the Escabrosa limestone at Bisbee, and the Pennsylvanian limestone near Ray to the lower part of the Naco limestone.

In the Bisbee quadrangle the distinction between the Mississippian and Pennsylvanian limestones proved practicable, although the plane of demarcation is not definite. In the Ray quadrangle a similar distinction might possibly be made, but no satisfactory basis for it appeared in the course of the field work, and it is doubtful whether its accomplishment would be worth the additional labor involved. The cliff-making lower members of the Tornado limestone are certainly Mississippian, and probably a considerable part of the upper member also belongs to that epoch.

The original thickness of the Tornado limestone is unknown, for the formation was extensively eroded before the eruption of the andesitic lavas and before the deposition of the Gila conglomerate. In the vicinity of Tornado Peak and along the east flank of the Tortilla Range the limestone at present must be fully 1,000 feet thick, and it may at one time greatly have exceeded this thickness.

NOMENCLATURE.

The foregoing descriptions have been written with special reference to the formations as they are displayed in the Ray quadrangle, but they apply without essential change to the adjoining Globe quadrangle. When that area was studied, about 11 years ago, little was known of the stratigraphy of this part of Arizona and it appeared impracticable, in so intricately faulted a district, to map the sedimentary rocks in as great detail as has since proved possible in the Ray quadrangle. In the Globe report the Scanlan conglomerate, Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite, while distinguished in certain geologic sections, were mapped together as the "Apache group" and the Devonian and Carboniferous limestone were mapped as the "Globe limestone." As none of the numerous small fault blocks into which the Globe district is divided afforded a complete geologic section, and as no quartzite was found overlying limestone, all the quartzite was supposed to belong to one formation (the Dripping Spring quartzite), and all the limestone was supposed to belong to the Devonian and Carboniferous "Globe limestone." The "Globe limestone," as mapped, therefore included a little Mescal limestone, and the Troy quartzite was not distinguished from the Dripping Spring quartzite. Had the existence of the Mescal limestone and Troy quartzite been known when the Globe report was written, these two formations would probably have been included in the definition of the Apache group.

As at present constituted, this group consists of the following formations, named in ascending order: Scanlan conglomerate, Pioneer shale, Barnes conglomerate, Dripping Spring quartzite, Mescal limestone, and Troy quartzite. All are apparently conformable and are provisionally assigned to the Cambrian.

SANTA CATALINA GEOLOGIC SECTION.

As the Santa Catalina Range, northeast of Tucson, is being carefully studied by Prof. C. F. Tolman, jr., for the United States Geological Survey, and as my own observations were confined to an excursion of only six days' duration, under his guidance, the treatment accorded in this paper to the geology is necessarily brief and general.

The central feature of the range, as worked out by Mr. Tolman, is a great post-Carboniferous intrusive mass of siliceous muscovite granite modified to a gneissic rock near its margins, surrounded by a zone of intense contact metamorphism in which rocks of widely different kinds have been conspicuously affected. The oldest rock cut by this granite is a coarse, porphyritic biotite granite which, apparently as a result of the later granitic intrusion, grades into augen gneiss, and locally this rock in turn has been transformed into a thinly fissile schist.

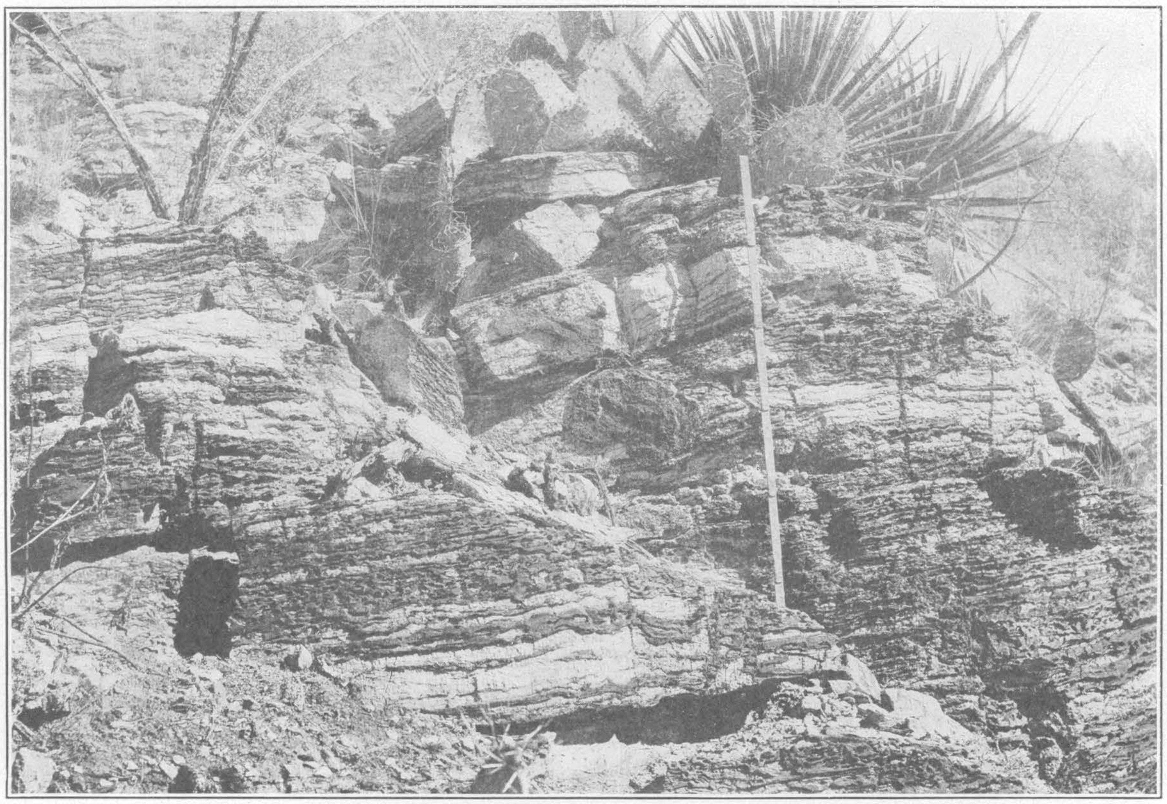
Resting upon a worn and weathered surface of the pre-Cambrian granite, as may be well seen on the east side of Oracle Ridge, north of Apache, is the Scanlan conglomerate, 10 to 12 feet thick, composed of imperfectly rounded pebbles of white quartz in a much silicified matrix. The conglomerate grades upward through several feet of very hard white quartzite into fine-grained sericite schists—the locally metamorphosed Pioneer shale. In some localities in the Santa Catalina Range the crystalline texture is so well developed that these altered shales might easily be mistaken for the pre-Cambrian Pinal schist. It may be noted in this connection that the Pioneer shale has been metamorphosed to crystalline schist by the intrusion of granodiorite at Troy, in the Ray quadrangle, also. The metamorphism there, however, is on a much smaller scale than in the Santa Catalina Range. Overlying the schist in the vicinity of Apache is the Barnes conglomerate, showing its well-rounded ellipsoidal pebbles. Its thickness here is about 12 feet. Although it is more silicified than the typical conglomerate of the Ray quadrangle, there can be little doubt of its stratigraphic identity. Southeast of Apache, on the east slope of the range, the Barnes conglomerate is overlain by a quartzite which is correlated with the Dripping Spring quartzite, although its character has been modified by the prevalent metamorphism. Stratigraphically above the quartzite is a formation that is probably the Mescal limestone. In a few places the limestone shows some of the cherty bands so characteristic of this formation near Ray, but as a rule the beds are much metamorphosed. Some have been squeezed and kneaded so that the chert layers have been drawn out into thin curly laminæ; others have been changed to crystalline schist or to fine-grained garnet-epidote rock. The vesicular basalt that overlies the Mescal limestone in the Ray quadrangle was not recognized in the brief examination made of the Catalina Range.

Above the Mescal limestone is a pebbly quartzite with bands of conglomerate and with thin, shaly worm-marked beds near the top; in all probability this is the Troy quartzite.

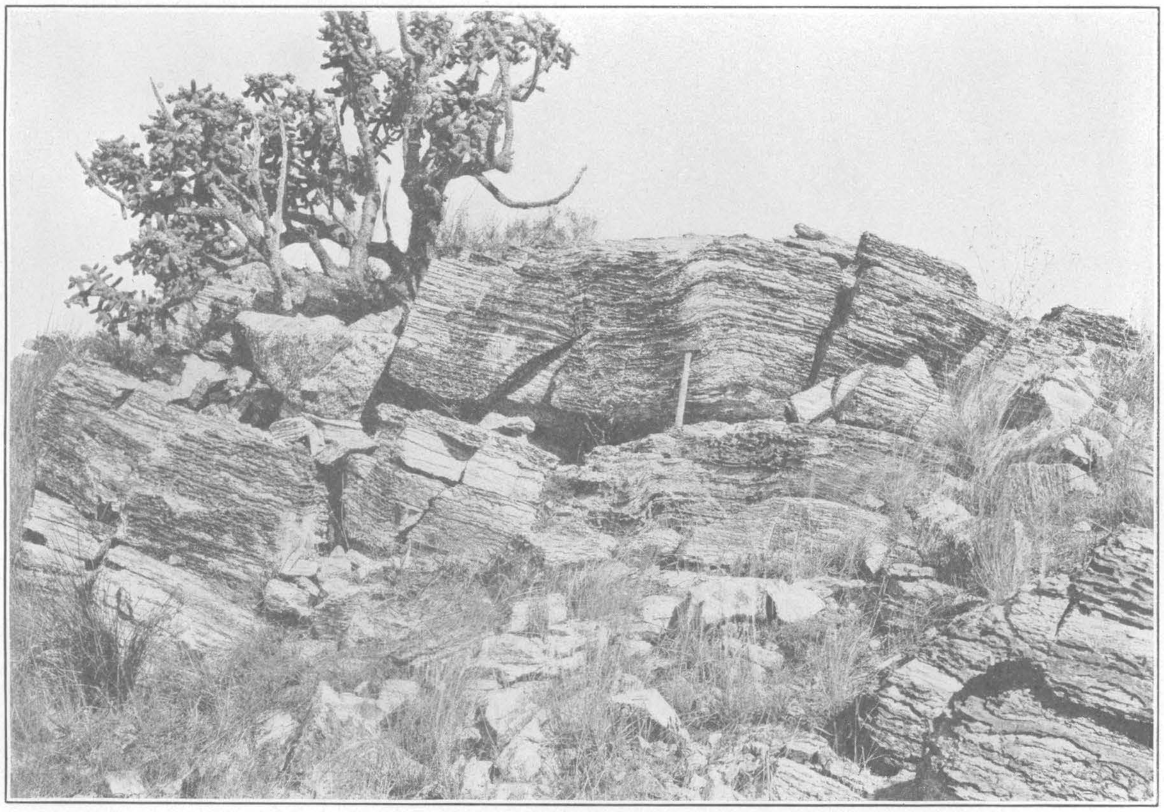
The quartzite is overlain by generally rather thin bedded Devonian limestones, from which Mr. Tolman has collected fossils, followed in ascending stratigraphic succession by the thicker-bedded gray Carboniferous limestone. Finally, these formations are unconformably overlain by a thick series of red shales, containing some impure sandy limestone, with a heavy limestone conglomerate at the base. These beds may possibly belong to the Manzano group,[1] but Mr. Tolman has not yet found any fossils in them.

In the short time devoted to the Santa Catalina Range no attempt was made to measure the thicknesses of the different formations. Disturbance and metamorphism render this a difficult task, but Mr. Tolman will doubtless attempt it before the completion of his work. The general impression obtained, however, was

[1] Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande valley, N Mex.: U. S. Geol. Survey Bull. 389, 1909.



A. TYPICAL EXPOSURE THREE-FOURTHS OF A MILE NORTHWEST OF MILITARY HILL, TOMBSTONE DISTRICT.



B. TYPICAL EXPOSURE ON ESCABROSA RIDGE, WEST OF BISBEE.

ABRIGO LIMESTONE IN THE MULE MOUNTAINS, ARIZ.

that the formations making up the Santa Catalina section do not differ greatly in their respective thicknesses from those at Ray.

BISBEE GEOLOGIC SECTION.

From Apache, in the Santa Catalina Mountains, to Tombstone the distance is about 70 miles, and from Tombstone to Bisbee about 20 miles. Between the Santa Catalina Range and the north end of the Mule Mountains, where Tombstone is situated, lies a country about which little geologic information is available. The principal mountain range in this interval is the Whetstone, southwest of Benson. These mountains were visited over 10 years ago by Dumble,[1] who reports over 1,300 feet of limestones and sandstones referable to the Carboniferous and 5,000 feet of sands and clays that he assigned to the Triassic. The range evidently is of much stratigraphic interest, especially in view of the fact that, as will presently be shown, the sections at Tombstone and Bisbee are considerably different from those of Ray and the Santa Catalina Range. Some carefully measured and described sections from the Whetstone Mountains would constitute a valuable contribution to the stratigraphy of Arizona, and as these mountains are readily accessible it is to be hoped that some geologist will before long find opportunity to study them.

A strictly geographic order of treatment would necessitate consideration of the section at Tombstone before that at Bisbee; but the latter was the first to be studied in detail and as it constitutes the type to which the Tombstone section conforms, it may conveniently be given priority of description here.[2]

Resting unconformably on the Pinal schist at Bisbee is the Bolsa quartzite, 430 feet thick, with a bed of conglomerate from 6 inches to a foot in thickness at its base. Most of the pebbles of this basal conglomerate are composed of white quartz and are less than 3 inches in diameter. The conglomerate is overlain, with no definite plane of division, by hard cross-bedded pebbly grits, the individual beds of which are from 10 to 20 feet thick, and above these lie thinner, finer-grained quartzites. The general color of the formation is rusty brown.

[1] Dumble, E. T., Notes on the geology of southeastern Arizona: Am. Inst. Min. Eng. Trans., vol. 31, pp. 696-715, 1902.

[2] For the original detailed descriptions of the formations at Bisbee see Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle Ariz.: U. S. Geol. Survey Prof. Paper 21, pp. 28-56, 1904.

Conformably overlying the quartzite is the Abrigo limestone, 770 feet thick. This formation consists mainly of rather thin bedded limestones, in part sandy and dolomitic, with some shale. A laminated structure, due to the alternation of layers of gray limestone, generally 2 or 3 inches thick, with still thinner sheets of chert, is a conspicuous feature of the formation. These chert bands, as may be seen from Plate XXX, *B*, are prominent on weathered surfaces, and the lithologic resemblance of the Abrigo to the Mescal limestone of the Ray quadrangle (see Pl. XXVIII, p. 140) is exceedingly close. The beds of the Abrigo are generally from 1 to 2 feet in thickness. Their prevailing color, as seen in large exposures, is dark greenish yellow.

In the typical Mount Martin section, near Bisbee, the Bolsa quartzite is immediately overlain by about 40 feet of thin-bedded, very cherty limestones, which break up on weathering into thin rusty plates. Above these are a few beds of gray limestone 2 feet in maximum thickness, alternating with fissile yellowish calcareous shales and with laminated cherty beds, such as have just been described. The upper 100 feet of the formation is made up of rather soft, sandy thin-bedded gray limestone, with one bed of harder gray limestone 6 feet thick about 40 feet from the top. The upper limit of the Abrigo formation is defined in the Mount Martin section by a bed of pure white quartzite about 8 feet in thickness. This quartzite is a persistent stratum and is found immediately underlying the Martin limestone, which carries Devonian fossils. Its thickness, however, is variable, and in places it grades downward into the upper sandy limestones of the Abrigo formation.

Analyses of two specimens of the Abrigo limestone are given below:

Partial chemical analyses of Abrigo limestone.

[W. F. Hillebrand, analyst.]

	1	2
SiO_2	11.80	12.53
Al_2O_3	*a* 2.15	*a* 1.04
Fe_2O_3, FeO *b*	1.08	1.26
MgO	.48	17.41
CaO	45.86	27.28

a Includes TiO_2 and P_2O_5 if present.
b Calculated as Fe_2O_3.

These analyses show that the different beds vary considerably in the ratio of lime to magnesia.

The oldest marine fossils in this region are found in the Abrigo formation and include trilobites, linguloid brachiopods, pteropods, and other early forms. The fossils collected from this formation were submitted to Dr. Charles D. Walcott, who reported that they are Middle Cambrian.

In the Mount Martin section the Martin limestone, carrying a Devonian fauna, overlies the Abrigo in apparent conformity. Its average thickness at Bisbee is about 325 feet. The beds most characteristic of the Martin formation are dark-gray hard, compact limestones which are generally well provided with fossils. Small brachiopods of rounded outline (*Atrypa reticularis* and *Spirifer hungerfordi*) are particularly abundant in some of the beds and give to the weathered surfaces of the limestone a nodular appearance which in the Bisbee quadrangle is peculiar to the Martin formation. A few of the beds are rich in corals, some of which weather out as distinct and in places well-silicified fossils, while others produce rather ill-defined white dendritic blotches in the dark limestone.

Associated with the preponderant dark limestones here and there are beds of lighter hue and some calcareous shales of a decided pinkish tint. These shales, which flake and crumble on exposure, are well exposed in the saddle just northeast of Mount Martin, where they carry abundant characteristic Devonian fossils. They occur also in several of the other areas of the Martin limestone, particularly on the southwest slopes of Escabrosa Ridge, but owing to their softness they are generally inconspicuous except where they are revealed by prospecting pits and tunnels. They belong in the lower half of the formation.

The upper limit of the Martin limestone is not everywhere sharply defined. In general it corresponds to the decided change from the dark compact limestones characteristic of this formation to the nearly white granular limestones, made up largely of crinoid stems, which characterize the Escabrosa formation. The actual plane of division, however, is rarely visible, owing to the tendency of the Escabrosa limestone to form cliffs and the consequent accumulation of talus over the contact. Even where no detritus conceals the relation of the two formations, there may be an intermediate zone 10 to 20 feet in thickness which contains no characteristic fossils and which it is impossible to assign with confidence, on purely lithologic grounds, either to the Martin or Escabrosa limestones.

The beds of the Martin limestone are usually less than 4 feet in thickness. They are thicker, on the whole, than those of the underlying Abrigo limestone, but thinner than those of the overlying Escabrosa limestone.

Chemically, the typical dark limestone of the Martin formation is a fairly pure calcium carbonate, containing a little silica but practically no magnesia.

The following species from the Martin limestone, collected in the course of the study of the Bisbee quadrangle in 1902, were identified by Prof. H. S. Williams:

Acervularia davidsoni (Milne-Edwards and Haime).
Pachyphyllum woodmani (White).
Cladopora prolifica (Hall and Whitfield).
Stromatopora erratica (Hall).
Cyathophyllum cæspitosum (Goldfuss).
Atrypa reticularis (Linné).
Cyrtia cyrtiniformis (Hall and Whitfield).
Dielasma calvini (Hall and Whitfield).
Schizophoria striatula (Schlotheim).
Productella speciosa Hall.
Delthyris consobrina (D'Orbigny).
Spirifer cf. S. jeremejevi (Tschernyschew).
Spirifer hungerfordi Hall.
Spirifer orestes Hall and Whitfield.
Spirifer cf. S. euryteines Owen (small specimen).
Spirifer whitneyi Hall.
Stropheodonta demissa (Conrad).
Stropheodonta (fragilis) perplana (Hall).
Strophonella cælata Hall.

The following specimens were too imperfect for specific determination:

Coral, several species.
Crinoid stem.
Bryozoa.
Terebratula? (small).
Minute brachiopod (?).
Loxonema.
Platyceras.
Pleurotomaria.
Bellerophon.
Leperditia.

Mr. Williams concluded that the fauna of the Martin limestone is Meso-Devonian, although he regarded it as having close affinities with the Neo-Devonian fauna of New York.[1]

[1] See extended note in U. S. Geol. Survey Prof. Paper 21, pp. 35–42, 1904.

Overlying the Martin limestone at Bisbee is the Escabrosa limestone, made up generally of rather thick-bedded, nearly white to dark gray granular limestones, which on close examination are seen to be made up very largely of fragments of crinoid stems. Near the base the individual beds are commonly 10 or 15 feet in thickness, but above the first 100 feet thicknesses of 1 to 5 feet are the rule, though there are a few more massive beds. The formation as a whole is a pure nonmagnesian limestone, containing practically no arenaceous sediments and only scattered irregular bunches and nodules of chert, usually in its upper part.

Fossils occur at many horizons from the bottom to the top of the formation, but, with the exception of small scattered corals and the abundant fragments of crinoid stems, they are rarely conspicuous and as a rule do not appear on weathered surfaces of the limestone. The general appearance of the Escabrosa formation is white or light gray, but some dark-gray beds occur, particularly near the top.

The fossils collected from the Escabrosa limestone were submitted to George H. Girty, who reported [1] that they probably represent the earlier half of Mississippian time, including the Kinderhook and Osage divisions. The following are some of the characteristic species listed by him, with his comment:

Menophyllum excavatum Girty.
Syringopora aculeata Girty.
Rhipidomella thiemei White.
Rhipidomella michelina L'Eveillé.
Leptæna analoga Phillips.
Schuchertella inequalis Hall.
Chonetes loganensis Hall and Whitfield.
Productus ovatus Hall.
Productus semireticulatis var.
Spirifer centronatus Winchell.
Spirifer mysticensis Meek.
Brachythyris cf. B. peculiaris Shumard.
Reticularia pseudolineata Hall?
Syringothyris carteri Hall.
Athyris lamellosa L'Eveillé.
Eumetria marcyi Shumard.
Pernopecten shumardanus Winchell.
Myalina keokuk Hall.
Phanerotinus paradoxus Winchell.
Euomphalus luxus White.
Platyceras sp.
Phillipsia peroccidens Hall and Whitfield.

Associated with some of the species in the above list were found others which probably indicate a slightly higher horizon than the Osage—in other words, one in the Meramec group. There are such forms as Lithostrotion sp., Meekopora sp., Archimedes sp., Pustula cf. *P. biseriata*, and Spirifer cf. *S. tenuicostata*. On the other hand, no fossils of a well-marked Chester type have been found, so that so far as the evidence at hand is concerned the upper Mississippian is missing. It is also true that many of the striking Osage forms have not been found—for example, *Schizophoria swallowi*, *Orthotetes keokuk*, *Spirifer grimesi*, and *Spirifer logani*—nor the wealth of crinoids which characterize this horizon in certain areas in the Mississippi Valley. I am disposed to regard the absence of these Osage forms as due to local conditions but also to believe that upper Mississippian time is really in large part unrepresented.

[1] Ransome, F. L., U. S. Geol. Survey Prof. Paper 21, pp. 46-54, 1904.

Measurements of the thicknesses of the Escabrosa limestone in different parts of the Bisbee quadrangle varied from 600 to 800 feet, the upper limit of the formation being difficult to determine with precision. The average thickness is taken as 700 feet.

The Naco limestone, which overlies the Escabrosa conformably and with no distinct lithologic change, is made up chiefly of light-colored beds, which consist essentially of calcium carbonate. The beds range in thickness from a few inches to 10 feet but are usually thinner than those of the Escabrosa limestone. They differ from the latter also in texture, the typical Naco limestone being compact and nearly aphanitic, ringing under the hammer, and breaking with a splintery fracture, whereas the Escabrosa limestone is usually more granular and crystalline and crumbles more readily when struck. There are, however, exceptions to this rule, dense aphanitic beds occurring here and there in the Escabrosa formation and granular crinoidal beds being not uncommon in the Naco limestone.

Fossils, particularly brachiopods, are much more abundant in the Naco than in the Escabrosa limestone, and in some places they make up a considerable part of individual beds and weather out conspicuously upon exposed surfaces.

While the greater part of the 3,000 feet or more of the Naco formation is made up of fairly pure gray limestone, certain thin beds of a faint-pink tint occur at different horizons and are often a useful means of distinguishing the Naco from the Escabrosa limestone. These pink rocks, which weathering usually shows to have an inherent lamellar or shaly structure, are very fine grained and compact in texture. They effervesce freely with cold dilute acid and are evidently composed chiefly of calcium carbonate. Examination of natural surfaces with a lens, however, shows the presence of minute quartz grains and tiny flakes of mica. Chert is not uncommon in the Naco formation; it occurs as irregular bunches and nodules in beds of otherwise pure limestone or as the result of the silicification of thin fossiliferous beds throughout their thickness. It is also particularly abundant along and near zones of fissuring and faulting.

According to Mr. Girty the fossils from the Naco limestone belong to two groups, one representing early and the other later Pennsylvanian time. The earlier fauna include the following:

Fusulina cylindrica Fischer de Waldheim.
Chætetes milleporaceus Milne-Edwards and Haime.
Derbya crassa Meek and Hayden.
Productus semireticulatus Martin.
Productus cora D'Orbigny.
Productus coloradoensis Girty.
Pustula nebraskensis Owen.
Postula semipunctata Shepard.
Marginifera wabashensis Norwood and Pratten.
Spirifer rockymontanus Macou.
Spirifer cameratus Morton.
Squamularia perplexa McChesney.
Spiriferina kentuckyensis Shumard.
Composita subtilita Hall.
Hustedia mormoni Marcou.
Dielasma bovidens Morton.
Phillipsia major Shumard.

The later fauna contains many species not yet described. The following forms have been discriminated:

Fusulina cylindrica Fischer de Waldheim.
Michelinia? sp.
Lophophyllum cf. L. profundum Milne-Edwards and Haime.
Echinocrinus, several sp.
Productus, semireticulatus type.
Postula cf. P. norwoodi Swallow.
Marginifera cf. M. wabashensis Norwood and Pratten.
Martinia sp.
Composita subtilita Hall.
Plagioglypta cf. P. canna White.
Worthenia sp.
Murchisonia?, several sp.
Euomphalus sp.
Omphalotrochus, several sp.
Cyclonema sp.
Orthonema sp.
Sphærodoma sp.
Bellerophon cf. B. crassus Meek and Worthen.
Euphemus sp.

This fauna, according to Mr. Girty, is closely related to that of the limestones of the Hueco Mountains, in western Texas.

From the preceding descriptions it appears that Paleozoic time is represented in the Bisbee quadrangle by beds having a total thickness of a little over 5,000 feet. Of these the lower beds, 430 feet thick, are quartzites and the remaining 4,570 feet of beds are so predominantly calcareous that they may be collectively designated limestones. The Pennsylvanian series is represented by at least 3,000 feet of strata (the Naco limestone), but only 340 feet (the Martin limestone) can be assigned to the Devonian, and the Silurian and Ordovician appear to be wholly without stratigraphic representation.

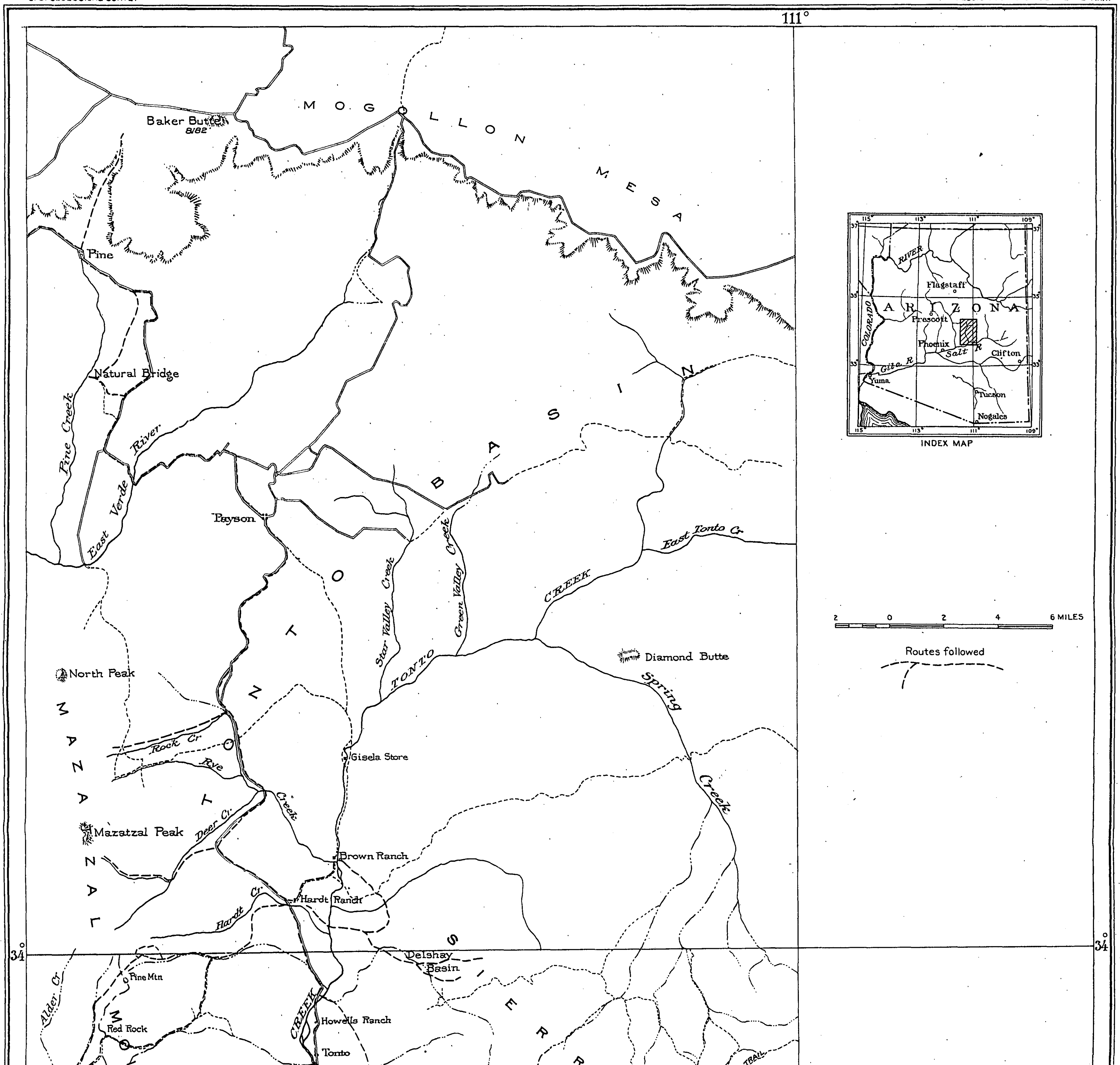
TOMBSTONE GEOLOGIC SECTION.

The Paleozoic section at Tombstone closely resembles that at Bisbee. The Bolsa quartzite has about the same thickness and character. The Abrigo limestone is 70 feet thinner than at Bisbee, and the bed of quartzite at its top also appears to be a little thinner than it is in the region to the south. The Martin limestone has a larger proportion of shale at Tombstone than at Bisbee, but contains similar coral-bearing beds and the fauna, according to Dr. E. M. Kindle, is the same as that of the Martin limestone at the type locality. The beds at Tombstone maintain the same total thickness, 340 feet, as at Bisbee.

The Mississippian division of the Carboniferous is approximately 500 feet thick at Tombstone, as against 700 feet at Bisbee, but owing to the lack of any plane of lithologic distinction between the Mississippian and the Pennsylvanian in this region these figures are not very reliable.

The Pennsylvanian (Naco) is well represented at Tombstone and consists almost exclusively of limestone. Of the fossils collected from the Naco limestone in the Tombstone district George H. Girty writes:

> The Pennsylvanian lots exhibit two faunal types which I understand occupy relatively higher and lower positions in the section. In the most characteristic lot of the upper horizon I recognized the following species:
>
> Echinocrinus sp.
> Productus ivesi Newberry.
> Composita subtilita Hall.
> Deltopecten vanvleeti Beede.
> Pleurotomaria? sp.
> Bellerophon aff. B. stevensianus McChesney.
> Euphemus sp.
> Omphalotrochus obtusispira? Shumard.
> Trochus? sp.
> Orthonema socorroense Girty.



OUTLINE MAP OF TONTO REGION, ARIZONA

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

The other lots add several species to this fauna, especially one or two large species of Schizostoma, a large Bellerophon, possibly *B. majusculus*, and a Murchisonia resembling *M. terebra*.

These two Pennsylvanian faunas bear a close relationship to the faunas of the Magdalena limestone and Manzano group of New Mexico, and it seems highly probable that the upper Naco limestone will correlate with the Manzano and the lower Naco with the Magdalena.

The fauna of the upper Naco is also related to a fauna found in the middle or upper part of the Hueco limestone. The lower Hueco fauna, while resembling in some respects that of the lower Naco, contains a good many species not yet found in the latter, and I am unable to state whether we have merely the same fauna with regional modifications or two faunas, one of which is older than the other. I rather incline to the former belief.

The thickness of the Naco formation at Tombstone has not been measured, but probably amounts to several hundred feet. The limestone was extensively eroded before the deposition of the Mesozoic beds that unconformably overlie it in part.

CLIFTON GEOLOGIC SECTION.

At Clifton, 90 miles east-southeast of Globe,[1] about 1,500 feet of apparently conformable Paleozoic beds rest unconformably on Pinal schist and coarse red granite. At the bottom of the stratigraphic column is the Coronado quartzite, 200 feet thick, with a layer of conglomerate at its base as much as 50 feet thick. A section of the quartzite southwest of Morenci is described by Lindgren[2] as follows:

Section of Coronado quartzite.

	Feet.
White quartzitic sandstone	50
Banded pink and maroon quartzitic sandstone, forming precipitous bluff	162
Quartzitic conglomerate	10
Sandstone	3
Quartzitic conglomerate (pebbles 1 inch in diameter)	8
Coarse sandstone (base)	10
	243

Above the Coronado quartzite lies the Longfellow limestone, 200 to 400 feet thick, which consists of cherty limestone in the upper part grading downward into shaly beds near the base. One of the sections given is as follows:

Section of Longfellow limestone one-fourth mile south of Modoc Peak.

	Feet.
Buff limestone	15
Quartzitic sandstone	10
Bluff of brownish-gray cherty limestone	140
Shaly limestone	90
Coarse gray sandstone	10
Sandy and shaly limestone (base)	115
	380

Fossils are scarce in the Longfellow limestone. In the lower shaly part were found a few small lingulas and other forms that, while insufficient for a certain determination of age, were regarded by Dr. C. D. Walcott as indicating probably the uppermost part of the Cambrian. Near the top of the formation were found gastropods and fragments of trilobites which E. O. Ulrich determined as early Ordovician.[1]. Lindgren places the Coronado quartzite in the Cambrian and the Longfellow limestone in the Ordovician.[2]

Resting upon the Longfellow limestone is the Morenci shale, consisting of a lower division of compact argillaceous limestone 75 feet thick and an upper division of dark clay shale about 100 feet thick. A few fossils were found in the lower division and were referred provisionally by Prof. H. S. Williams to the Devonian.[3]

Overlying the Morenci formation is the Modoc limestone, 180 feet thick, of Mississippian age.[4] North of the exposures of the Modoc limestone and not in contact with it is a limestone formation 500 feet thick which Lindgren has called the Tule Spring limestone. It carries both Mississippian and Pennsylvanian fossils, and the lower 200 feet of the formation is regarded by Lindgren as in a general way equivalent to the Modoc limestone. The Tule Spring limestone is limited above by the pre-Cretaceous unconformity.

ROOSEVELT GEOLOGIC SECTION.

The gorge through which Salt River, after passing the Roosevelt dam, traverses the south end of the Mazatzal Range (see Pl. XXXI), affords an excellent section of the beds from the Mississippian down to the granite. This

[1] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, 1905. See also U. S. Geol Survey Geol. Atlas, Clifton folio (No. 129), 1905.
[2] Op. cit. (Prof. Paper 43), p. 60.

[1] Op. cit. (Prof. Paper 43), p. 65.
[2] Idem, p. 59.
[3] Idem, p. 69.
[4] Idem, p. 72 (list of fossils).

exposure has been very briefly noted by Lee,[1] whose diagrammatic section of the beds is reproduced here as figure 11. The explanatory lettering that evidently was intended to accompany the diagram was inadvertently omitted from Mr. Lee's paper, but the bed marked 1 is obviously Quaternary material, 2 is intended for Carboniferous limestone, 3 is the Troy quartzite, 4 is the Mescal limestone, 5 is the Dripping Spring quartzite with the Barnes conglomerate at its base, 6 and 9 correspond to the Pioneer formation, and 10 is the Scanlan conglomerate. The numerals 7 and 8 designate a thick sill of diabase in which the thin layer (shale?) is probably not so persistent as is indicated, and 11 is coarse pre-Cambrian granite. Lee[2] cites a personal communication from Dr. C. D. Walcott to the effect that "the Carboniferous limestones rest directly and unconformably upon the quartzites and argillites of the Algonkian" and agrees that all the beds below the supposed unconformity (which he did not himself see[3]) are Algonkian.

The base of the sedimentary series is exposed about half a mile downstream from the dam, where the Scanlan conglomerate, here 30 feet thick, rests on an erosion surface of coarse red granite. This color is the result of pre-Cambrian weathering, and is characteristic of this old surface throughout central Arizona. The red tint generally fades to gray a short distance from the contact. The surface shows gentle undulations, and the conglomerate is probably variable in thickness. Its dip is 35° NE. The pebbles, unlike those in the typical Scanlan conglomerate of the Ray section, are well rounded and are as much as 9 inches in diameter. They are composed of white quartz, brown fine-grained vitreous quartzite, and a little red jasper. They lie close together in a matrix of dull red-brown coarse sandstone. On the whole, the conglomerate locally resembles the typical Barnes conglomerate of the Ray quadrangle more than it does the Scanlan conglomerate of the same area, of which, however, it is undoubtedly the stratigraphic equivalent.

The Scanlan conglomerate is conformably overlain by rather coarse brown cross-bedded arkosic sandstone, flecked with small light spots, like those in the typical Pioneer shale, and containing a few small pebbles. The lowest three beds of this sandstone are each about 10 feet thick and are separated by partings of maroon shale. Above them both the sandstone beds and the layers of shale become thicker for about 140 feet, to the base of a great diabase sill, probably 700 to 800 feet thick. Despite the size of this intrusion the shales above and below it show no metamorphism other than slight baking and hardening. Above the diabase lies about 100 feet of typical spotted maroon Pioneer shale.

The shale is overlain by the Barnes conglomerate. The pebbles are smaller than those in the typical conglomerate of the Globe-Ray region, most of them being less than 4 inches in diameter, and there is a rather large proportion of sandy matrix. As exposed in the cliffs, high above the river, the Barnes conglomerate appears to be rather better developed

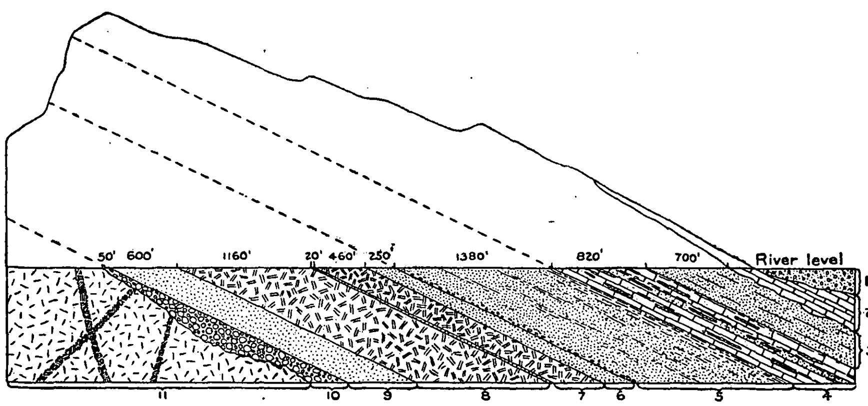


FIGURE 11.—Section through Salt River gorge near Roosevelt, Ariz., looking northwest. (After W. T. Lee.) See text for explanation.

[1] Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, pp. 96–98, 1905.
[2] Idem, p. 96.
[3] Oral communication.

than in the roadside exposure studied, where its thickness is from 15 to 20 feet.

Overlying the Barnes conglomerate is the Dripping Spring quartzite, which has an estimated thickness of 500 to 600 feet. For about 140 feet above its base the banded reddish-brown quartzite is separated rather indistinctly by thin partings of dark-red shale into beds 10 feet or less in thickness. Above this zone the beds are thinner and show some faint cross-bedding. The upper 180 feet of the formation consists of thinly laminated striped dull-red and black quartzite, which as a rule forms a cliff. The cliff dwellings of the Tonto National Monument, about 4 miles southeast of the dam, are in these upper beds. So far as seen the Dripping Spring quartzite at Roosevelt, as well as near Ray, is free from pebbles.

On top of the Dripping Spring quartzite is the Mescal limestone, which is very well exposed at Roosevelt, especially along the Phoenix road from the dam to a point about 100 yards beyond the first sharp turn to the east. The beds dip 25° NE., and the plane of contact between the Dripping Spring quartzite and the Mescal limestone, if projected across the gorge, would intersect the dam about halfway between the top and the bottom.

The Mescal near the Roosevelt dam consists of hard dolomitic cherty limestone in beds that are for the most part less than 2 feet thick, with little or no shaly material. The roughly parallel but wavy and irregular layers of chert so characteristic of the formation farther south are equally conspicuous near Roosevelt in weathered exposures transverse to the bedding planes. The general color of the formation is darker than at Ray, and the chert bands near the base are black and flinty. On fresh fractures the Mescal limestone is gray, pink, or yellow. The local thickness of the formation is about 300 feet. Overlying the limestone, as at Ray, is a flow of rusty basalt, from 40 to 60 feet thick, as exposed near the east end of the dam, and vesicular both at top and bottom.

Overlying the basalt flow is the local equivalent of the Troy quartzite, which here may be more appropriately called the Troy sandstone. As exposed along the road between the dam and the cement quarry, this formation is made up as follows:

Section of Troy sandstone.

	Feet.
3. Cross-bedded pebbly sandstone. Lower beds massive and weathering dark reddish brown. Lower massive bed near dam beautifully striped in red and gray. Upper beds thinner, mostly under 2 feet, with calcareous cement	100
2. Cross-bedded pebbly sandstone, with layers of brown, micaceous sandy shale	40
1. Dark-brown shale grading upward by interbedding into sandstone	20
Base.	

The Troy sandstone at Roosevelt is much thinner, therefore, than in the Ray-Globe region.

Overlying the Troy with no conspicuous difference in general appearance is a series of generally rather thin-bedded limestones and sandstones or quartzites. The lower beds are very compact gray limestones, which are succeeded by impure sandy limestones interbedded with calcareous sandstones and some quartzite. The topmost bed is shale which weathers to thin yellow flakes and is considered to be lithologically and stratigraphically identical with the yellow shale that is believed to mark the top of the Devonian in the Ray-Globe region. The formation as a whole is more sandy than the Martin limestone of the Ray quadrangle and is less fossiliferous. A few fossils were collected in 1912 from the top of the sharp hill just east of the dam and south of the cement quarry, but Dr. Kindle found that only one species, probably *Schizophoria striatula* (Schlotheim), is represented. He writes, in a personal letter:

> Before offering a final opinion as to the age of the fauna represented by this shell I would like to see another collection, including other species. I am inclined provisionally to refer the beds represented by this single species to the Devonian.

The locality was again visited in 1914 and additional fossils were collected. Edwin Kirk, of the United States Geological Survey, to whom they were submitted, lists them as follows:

Cladopora sp.
Schizophoria stratula var. australis Kindle.
Schuchertella sp.
Camarotœchia contracta Hall (?).
Camarotœchia sp.
Spirifer whitneyi var. animasensis (Girty).
Modiomorpha sp.

Mr. Kirk remarks that this fauna can be correlated with that of the Martin limestone of Bisbee and that of the Ouray limestone of Colorado. He states that there can be no doubt of the Devonian age of the material.

No measurement of the Devonian near Roosevelt was made, but the thickness is estimated roughly at 300 feet.

Overlying the yellow shale at the top of the Devonian beds is the light-gray pure and comparatively massive Carboniferous limestone. This is the rock that was quarried for cement during the construction of the dam. It forms the little knoll northwest of the dam on which stands the hotel. Fossils were collected by W. T. Lee from the limestone near Roosevelt and from Windy Hill, about 5 miles east of the dam. G. H. Girty,[1] to whom they were referred, identified the fauna as early Mississippian and lists the following forms:

Zaphrentis sp.
Menophyllum excavatum Girty.
Cyathophyllum sp.
Syringopora surcularia Girty.
Syringopora aculeata Girty.
Leptopora typa Winchell.
Crinoidal fragments.
Rhipidomella sp.
Schuchertella inæqualis Hall.
Productus ovatus Hall.
Camarotœchia metallica White.
Spirifer centronatus Winchell.
Spirifer sp.
Platyceras sp.
Bellerophon sp.
Composita humilis?
Fish tooth.

It appears from the foregoing description that the stratigraphic column at Roosevelt is composed of the same formational units as that of the Globe-Ray region and that the Mississippian limestone lies conformably on the Devonian.

CANYON CREEK GEOLOGIC SECTION.

The region adjacent to Fort Apache, northeast of Roosevelt, received some attention from the geologists of the Wheeler Survey[2] and was later described by Reagan.[3] Marvine at least, in his trip from Fort Apache to the Gila Valley, undoubtedly saw the two quartzites that have since been called the Dripping Spring and Troy quartzites, but he refers all exposures of both to the "Tonto sandstone." Gilbert also applies the same name to all the arenaceous rocks below the Redwall limestone, but it is possible that he had only distant views of the Dripping Spring quartzite, which apparently does not appear in the plateau escarpment. Reagan describes a number of stratigraphic sections and notes certain sediments as being unconformable under the "Tonto sandstone" and therefore of Algonkian age. These older rocks probably include the Pioneer shale, but how much more is not clear from his descriptions. Neither is it clear that he has in all places applied the name "Tonto sandstone" to the same formation. Attempts to identify in his published sections the formations discriminated in the Roosevelt and Grand Canyon sections have met with little success.

One of Gilbert's sections (No. IX, Aubrey Cliff, at Canyon Creek) interpreted in the light of present knowledge of Arizona stratigraphy is given in the correlation chart of Plate XXV (p. 136). The original description is as follows:

	Feet.
1. Coarse uncemented gravel, of quartzite and gneiss bowlders	20
2. Massive cross-bedded yellow sandstone	525
3. Compact gray limestone; *Spirifer cameratus*	65
4. Red and purple sandstone, soft at top, massive below	500
5. Alternation of gray limestone and red shale: *a.* Limestone, 5 feet. *b.* Unseen; shale (?), 100 feet. *c.* Limestone, *Athyris subtilita*, 10 feet. *d.* Red calcareous sandstone, 4 feet. *e.* Shale, 40 feet. *f.* Limestone, 4 feet. *g.* Unseen; shale (?), 25 feet. *h.* Massive limestone, 10 feet. *i.* Unseen; shale (?), 75 feet. *j.* Limestone, 2 feet. *k.* Unseen; shale (?), 50 feet.	325
6. Sandstone: *a.* Brown to red, coarse vitreous sandstone, massive to shaly, 100 feet. *b.* Gray fine-grained sandstone, weathering red, falling apart in angular blocks, 75 feet. *c.* Shaly calcareous sandstone, 75 feet. *d.* Vitreous, red, purple, and white sandstone, 150 feet. *e.* Coarse siliceous conglomerate, 25 feet.	425
7. Hornblende rock and schists; unconformable	500+
	2,360+

In this section No. 2 is unquestionably the Coconino sandstone, 3 and 4 are probably the

[1] Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, pp. 97-98, 1905.
[2] Gilbert, G. K., U. S. Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 163-165, 1875. Marvine, A. R., idem, pp. 215-225.
[3] Reagan, A. B., Geology of the Fort Apache region in Arizona: Am. Geologist, vol. 32, pp. 265-308, 1903.

Supai formation, although it is thinner than might be expected. 5 presumably is the Redwall, and 6 is possibly the Tapeats ("Tonto") sandstone, although it appears to be too thick for that formation. The section as a whole conforms to the Grand Canyon type and is decidedly different from the Roosevelt and Ray-Globe sections.

Gilbert[1] gives a section on Carrizo Creek, which is about 20 miles east of Canyon Creek, that indicates the presence of 1,200 feet of Supai rocks above the Redwall, but his descriptions suggest that there may be some difficulty in determining the stratigraphic limits of the formations in this region. Another of his sections (No. XI) measured north of and near Fort Apache gives 1,390 feet of beds that from his description would probably now be identified as the Supai formation.

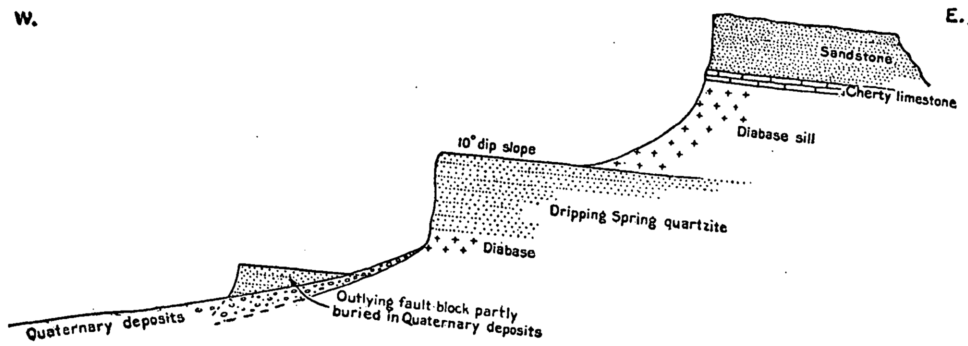


FIGURE 12.—Diagrammatic section across the Sierra Ancha, Ariz., near Aztec Peak.

SIERRA ANCHA AND MAZATZAL RANGE.

CARR'S RANCH AND VICINITY.

The western front of the Sierra Ancha, as seen from Roosevelt, is bold and precipitous. Even so distant a view reveals very clearly the general structure of the range—that of a block, probably a fault block, uptilted along its western margin. Dark cliffs of red-brown quartzite in the lower part are succeeded along the crest by beds so much lighter in hue that they suggested at first the presence of the Carboniferous limestones.

An ascent of the range was made from Roosevelt in 1914 by way of Carr's ranch to Aztec Peak, and its general structure was found to be that indicated diagrammatically in figure 12. The oldest formation seen in this traverse is the Dripping Spring quartzite. This forms the lower line of cliffs that are conspicuous along the west face of the range for 7 or 8 miles north of Salt River. It has been considerably faulted, so that in places isolated down-dropped blocks lie in front of the main escarpment, and has also been intruded by diabase. The bottom of the quartzite was not seen, but the beds exposed were estimated to have a thickness between 300 and 500 feet.

Above the quartzite is an enormous sill of diabase probably 1,000 feet or more in thickness, dipping to the east, like the quartzite, at 10° to 15°. In consequence of its greater susceptibility to decomposition and erosion, the diabase has weathered back, leaving a broad dip-slope bench on the quartzite, which is followed for many miles by the road from Salt River to Carr's ranch. (See fig. 12.) Ravines leading down from the upper part of the range cross this bench and in the quartzite become deep, narrow chasms with vertical walls. A few included masses of altered Mescal limestone were noted in the diabase, and remnants of the limestone appear to overlie the igneous rock in some places. Evidently here, as in the Globe-Ray region, the principal diabase intrusion took place at the Mescal horizon.

Carr's ranch is situated on the diabase sill at an elevation of about 5,600 feet. A few miles northeast of the ranch on the north side of Workman Creek, a section of the beds that overlie the diabase was examined. The results are as follows, the thicknesses having been determined by aneroid barometer.

[1] Gilbert, G. K., op. cit., p. 164.

Section in Sierra Ancha.

Top of ridge.	Feet.
8. Hard white quartzitic sandstone, with streaks of well-rounded quartz pebbles, none of which are over 2 inches in diameter. Weathers light red or pinkish brown. Beds 5 to 6 feet thick near base but stratification less distinct above. Some cross-bedding at low angles. Forms a cliff	200
7. Fairly hard coarse to pebbly pink-buff sandstone. Grains smaller than peas. Grades downward into No. 6	75
6. Massive, generally fine-grained gray sandstone. Weathers dingy white and forms a rough ledgy slope above cliff noted below. Fairly soft and could be easily worked as a building stone. Texture uneven, owing to imperfect mixing of grains of different size	75
5. Massive fine-grained pink to buff sandstone. Forms a cliff. Contains well-rounded grains of pink feldspar and white quartz, the largest the size of mustard seeds. Layers of quartz pebbles as much as 2 feet thick in upper 100 feet. Pebbles fairly well rounded and 4 inches or less in diameter, in places scattered through the sandstone	200
4. Fine-grained homogeneous pinkish sandstone. Bedding not distinct. Weathers in slabs and as a rule forms a steep slope	300
3. Fine-grained red-brown, rather flaggy sandstone. Rests directly on basalt. Contains flakes and thin layers of red shale	50
2. Vesicular basalt flow, forming a red-brown bluff. Thickness not closely determined, probably about	50
1. Thin-bedded cherty limestone, considerably metamorphosed and containing serpentine, tremolite, and pyrite. Not well exposed. Thickness uncertain, probably about	250
Intrusive diabase at base.	

From the top of this section to the summit of Aztec Peak, on Baker Mountain, the difference in elevation is about 200 feet. This interval appears to be occupied by a massive medium-grained quartzitic sandstone, on which weathering brings out a lamination parallel with the bedding. In places this sandstone is rusty and contains little ball-like concretions an inch or two in diameter. Although no unconformity was detected, the possibility of a stratigraphic break between this sandstone, or some part of it, and the sandstones noted in the preceding section can not be denied.

The metamorphosed limestone above the diabase at the base of the section is probably the Mescal limestone. Above it is at least 900 feet of sandstone, which is supposed to be the stratigraphic equivalent of the Troy quartzite.

GREENBACK VALLEY AND VICINITY.

About 9 miles west-northwest of Carr's ranch, also on the west slope of the Sierra Ancha, is Greenback Valley, a little basin about 2 miles in diameter; floored chiefly with diabase and inclosed in part by cliffs of Dripping Spring quartzite. The quartzite, as in parts of the Globe-Ray region, has been extensively invaded by the diabase, both as thick sheets and as crosscutting masses. In places blocks of the quartzite strata were evidently at one time completely enveloped in the diabase magma.

The basal rock in this vicinity is a coarse porphyritic biotite granite. This is exposed in the deep gorge of Sallymay Creek, 5 miles east of the valley, and at several places along the west base of the range between Greenback Valley and Tonto Creek.

Resting upon the granite on Sallymay Creek is a basal conglomerate about 6 feet thick where seen. The lower 3 feet is coarse, with well-rounded pebbles of white quartz, pink quartzite, and red jasper, the largest 8 inches in diameter, in an arkosic matrix. Overlying the conglomerate is a brownish-red arkosic quartzite containing abundant particles of pink feldspar. Between some of the quartzite beds are thin layers of sandy shale. This quartzite is probably the stratigraphic equivalent of the Pioneer shale farther south. It is at least 150 feet thick and may be considerably thicker. Overlying it is a sheet of diabase, on top of which is the cliff-making Dripping Spring quartzite. Whether the Barnes conglomerate is present above or below the diabase on Sallymay Creek was not ascertained in the short time spent in this locality.

Just north and east of Greenback Valley the range exhibits well the generally broad-topped character which originally suggested its Spanish name. From the brink of the westward-facing cliffs the surface slopes gently eastward, much of it being a dip slope on the tops of the Dripping Spring quartzite. Here and there are remnants of thin-bedded cherty limestone, presumably the Mescal limestone. The top of Greenback Mountain, east of Greenback Valley, is such a remnant.

On the north slope of Chubb Mountain, near the point where a trail from Greenback Valley descends a very steep slope into the canyon of Sallymay Creek, the diabase is overlain, with igneous contact, by a little pink quartzite, which is succeeded conformably by 15 to 20 feet of hard conglomerate. This closely resembles the typical Barnes conglomerate, but here, as in other places near Greenback Valley, the Dripping Spring quartzite and older formations have been so broken and displaced by the diabase intrusion that it is not always possible to be sure of the stratigraphic relations without much more detailed work than can be done in a hasty reconnaissance.

From Clanton's ranch, on Tonto Creek, about 4½ miles above Cline, another traverse was made to the crest of the Sierra Ancha, which was reached at a point 4 miles north-northwest of Greenback Valley and 7 miles southeast of Gun Creek. The western slope of this part of the range was found to consist of numerous fault blocks, each consisting of the basal granite, Scanlan conglomerate, Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite, with great sills of diabase, all lying nearly horizontal. The faults are apparently normal and form a series of steps leading to the crest of the range, which at the locality visited is a plateau nearly 6,000 feet in altitude, corresponding to the upper surface of the Dripping Spring quartzite and surmounted by a few patches of cherty limestone, probably the Mescal. The Scanlan conglomerate is 5 to 6 feet thick and is made up of fairly well rounded pebbles as much as 8 inches in diameter. It rests on the same coarse red granite that is seen in Sallymay Canyon. Above the Scanlan conglomerate is some typical Pioneer shale, but higher in the section the shale becomes interbedded with quartzite, and, as the Barnes conglomerate does not appear to be strongly developed, the plane between the Pioneer shale and the Dripping Spring quartzite was not very satisfactorily determined in the short time given to the examination. The Pioneer formation is probably not over 200 feet thick in this part of the range. The Dripping Spring quartzite, however, is prominently developed and generally forms a horizontally banded red-brown cliff. It has a local thickness of about 500 feet.

From Roosevelt northward the valley of Tonto Creek, deeply filled with fluviatile and lacustrine deposits, is 4 or 5 miles in breadth and contains a recent alluvial flood plain a mile or so wide along the creek. Near the mouth of Gun Creek this valley contracts to a gorge in schist and a sharp ascent of about 500 feet over hills of pre-Cambrian schist leads up to Tonto Basin. This is an irregular depression whose hilly floor, ranging from 3,000 to 6,000 feet in altitude, is bounded very definitely on the north by the great escarpment of the Mogollon Mesa and is less completely closed in on the west by the linear crest of the Mazatzal Range and on the southeast by the northern part of the Sierra Ancha. The floor of the basin is composed mainly of granite and other pre-Cambrian intrusive rocks, with some schist, covered in part by Tertiary and Quaternary volcanic rocks and gravels.

DELSHAY BASIN.

Delshay[1] Basin is a well-marked upland depression, about 3 miles in diameter, on the west slope of the Sierra Ancha near the north end of that range. It is drained through deep canyons by Gun Creek and its tributaries. The basin, whose floor has a general altitude of 4,500 to 5,000 feet, is best reached by road and trail from Hardt's ranch, in Tonto Basin.

The fundamental rocks between Hardt's ranch and Delshay Basin are crystalline sericitic and greenstone schists, which strike in general northeast and dip northwest at high angles. These are cut by dikes of granite porphyry and of rhyolite that is in places schistose. A bold ridge of the schistose rhyolite forms the west wall of the basin, and Gun Creek flows in a wild gorge along its eastern base. Closely associated with the schist are masses of quartzite that lie unconformably beneath the nearly horizontal Cambrian quartzites and are described on pages 157–159. Some beds of magnetitic quartzite, striking northeast, form part of the schist series in Delshay Basin, and occupy a belt perhaps a quarter of a mile wide and at least a mile in length. The deposits appear to be lenticular, and the individual masses are 50 feet in maximum width. There are all gradations between nearly pure magnetite and dark ferruginous quartzite.

[1] This name, in use by the cattlemen of the region, is said to be that of a former Indian chief. Some uncertainty attaches to the spelling, which is that given to me at Hardt's ranch.

The material was evidently laid down in pre-Cambrian time as a magnetitic sand and has been folded and squeezed with the other rocks of the schist complex.

Southeast of the magnetite belt in Delshay Basin is a belt from 1 to 2 miles wide of a peculiar conglomerate that is clearly a part of the schist complex, has been thoroughly squeezed, and is decidedly schistose. The cleavage planes stand nearly vertical. The "pebbles" are mostly flat flakes of slate and schist, as much as 8 inches long, with a few round pebbles of harder material. The matrix consists of grains of quartz and pink feldspar. Clearly the schistose terrane in this region has a complex history and records more than one period of dynamic metamorphism. To the east of the schist conglomerate Delshay Basin is floored with coarse red pre-Cambrian granite. Presumably the schist conglomerate was originally deposited on this granite, but the contact was not seen.

On the east and south the rocks that have been mentioned as exposed in the floor of Delshay Basin are overlain unconformably by nearly horizontal beds, whose edges are exposed in the steep slopes and cliffs that shut in the basin on those sides. A section of these beds up the east wall of the basin is as follows, the thicknesses being approximate only:

Section on east side of Delshay Basin.

	Feet.
Crest of Sierra Ancha.	
13. Purplish brown calcareous shale, apparently interbedded with impure cherty limestone. Slope littered with rusty spongy chert	125
12. Smooth slope with no exposures. Fragments of thin-bedded rusty sandstone and shale with some very impure dolomitic limestone. Abundant fragments of dark vesicular chert. A little decomposed igneous material. Small outcrop of light gray limestone at base	60
11. Smooth slope with few outcrops. Rusty cherty detritus in soil, with fragments of thin-bedded sandstone and shale	40
10. Fine-grained, rather rusty quartzitic sandstone. Beds a little thicker than in No. 9, the maximum being 3 feet	100
9. Thin-bedded flaggy sandstone with some shale. Weathers in buff, brown, and rusty shades. Some beds show worn casts. Forms gentle slope with poor exposures	100
8. Massive pink quartzitic sandstone, weathering with pits like No. 6. Prominent cliff maker	75
7. Fine-grained pink to yellow-brown quartzitic sandstone. Like No. 6, but in thinner beds; forms slope	25
6. Massive pink quartzitic sandstone with, in lower part, a few rather angular pebbles of white quartz as much as 4 inches in diameter. Prominent cliff maker. Weathers with numerous round but rather irregular pits, mostly less than 1 inch across	50
5. Conglomerate with rather angular pebbles of white quartz. Thickness apparently variable, where seen about	2
4. Massive fine-grained red-brown sandstone. Beds 12 feet or more thick, but bedding inconspicuous. Some cross-bedding at low angles, not over 30°. Less noticeably arkosic than beds below. Forms cliffs	150
3. Apparently fine-grained red-brown sandstone. Exposures in part poor or lacking	100
2. Coarse red-brown arkosic, quartzitic sandstone in beds as much as 6 feet thick. Contains ill-defined layers of conglomerate with pebbles mostly under 1½ inches and not well rounded. Some layers of spotted red shale	150
1. Conglomerate with poorly rounded pebbles of white quartz in a coarse arkosic matrix. Pebbles mostly under 2 inches	3
(This conglomerate is apparently better developed and has larger pebbles in neighboring parts of the same ridge, as indicated by blocks in streamways.)	
Bottom of section coarse red granite, of which upper 4 or 5 feet appears to have been disintegrated before overlying sediments were laid down.	

The foregoing section is not readily divisible into the units of the Globe-Ray section, and evidently the changes that take place in the older Paleozoic sediments along the Sierra Ancha require something more than a few traverses to determine their character and significance. A careful stratigraphic study carried continuously along the range would undoubtedly yield interesting results. Nevertheless, it is believed that the section given is much more closely related to the Globe-Ray section than to the sections farther north that will presently be described. The thin-bedded impure cherty limestone at the top of the section is probably the stratigraphic equivalent of the Mescal limestone, and the sandstones and conglomerates below probably represent the Scanlan conglomerate, Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite. The great intrusions of diabase are not represented in the part of Delshay Basin seen, and the absence of this rock may account for the fact that the arenaceous beds are less quartzitic than farther south and lack certain other features that are characteristic of these rocks in the southern part of the range, at Roosevelt and in the Globe-Ray region.

PRE-CAMBRIAN SEDIMENTS OF THE NORTHERN SIERRA ANCHA AND OF THE MAZATZAL RANGE.

One of the most interesting of the results of the two reconnaissance trips made into the region adjacent to Tonto Basin was the recognition of a thick series of quartzites, conglomerates, and shales that is unconformably beneath the Apache group and its stratigraphic equivalents. A brief reference to these rocks has already been published.[1]

The unconformity between these pre-Cambrian strata and the nearly horizontal Paleozoic beds is clearly shown just north of Delshay Basin. Here a prominent bold hill lying just east of Gun Creek and north of a tributary that is locally known as Sheep Basin Draw is composed of this older quartzite. The rock was not closely examined at this locality, but the beds are evidently some hundreds of feet in total thickness and are complexly folded and faulted. Just east of this hill, which closes Delshay Basin on the north, are the cliffs in which are displayed the nearly horizontal beds described in the section on page 156. These beds were not seen at this locality in actual unconformable contact with the older quartzite, but the contrast in character and structure is so obvious that no doubt is entertained of the existence of a pronounced unconformity. The relation of the older quartzite to the schist terrane is apparently intimate, and the quartzite has shared to some extent in the vigorous deformation to which the schistose rocks have been subjected.

The pre-Cambrian strata occur also in the northern part of the Mazatzal Range and were here more closely examined. Mazatzal Peak, about 8,000 feet in altitude, is composed chiefly of these rocks, which appear to constitute the higher portion of the range from this rugged summit northward.

From Hardt's ranch a traverse was made up Deer Creek, which heads south of Mazatzal Peak and flows eastward into Rye Creek, a tributary of Tonto Creek. The lowest and oldest rocks exposed on Deer Creek are schists. These schists, with those exposed at Hardt's ranch and in Delshay Basin, are part of a northeasterly belt that crosses the Mazatzal Range obliquely between the pre-Cambrian granite of Mount Ord and the quartzite mass of Mazatzal Peak and apparently continues northeastward past the north end of the Sierra Ancha. The descriptions given by Reagan[1] are not quite clear on this point, but the belt of schistose rocks, irregularly overlapped in places by younger formations, appears to extend eastward across the upper parts of Cherry, Canyon, and Cibicu creeks, beyond which it probably passes under the horizontal Paleozoic beds of the Arizona Plateau. Where seen in the Tonto region these schists have considerable lithologic variety. They include sericite schist, greenstone schist, brown and dark-gray slates, schistose grits and conglomerates, hematitic schist, thin-bedded dolomite and red jasper, and beds of quartzite or quartz schist. Associated with these rocks are some rhyolite, generally schistose in part, and small masses of other ancient igneous rocks. Where it crosses the Mazatzal Range the belt of exposures is about 5 miles wide. To the northeast, where it crosses Tonto Basin and extends past the north end of the Sierra Ancha, the area of schistose rocks is probably at least 15 miles wide. The belt contains the quicksilver deposits of the Mazatzal Range.[2] It is of especial interest in connection with the subjects discussed in the present paper, as it appears to mark a pronounced change from north to south in the character of the pre-Devonian Paleozoic sections of this part of Arizona. This will be brought out more fully in subsequent pages.

At an altitude of about 5,600 feet on the north side of the middle fork of Deer Creek the basal bed of the pre-Cambrian sedimentary beds rests on red oxidized rhyolite that shows well-developed flow structure. The relation of this old rhyolite to the schists was not ascertained, but it is probably a part of the schist complex. The beds strike N. 33° E. and dip about 70° NW. This attitude agrees fairly well with the general strike and dip of the schists and suggests that the beds about to be

[1] Ransome, F. L., Quicksilver deposits of the Mazatzal Range, Ariz.: U. S. Geol. Survey Bull. 620, pp. 114-117, 1915 (Bull. 620-F).

[1] Reagan, A. B., Geology of the Fort Apache region in Arizona: Am. Geologist, vol. 32, pp. 265-308, 1903.

[2] Ransome, F. L., Quicksilver deposits of the Mazatzal Range, Ariz: U. S. Geol. Survey Bull. 620, pp. 111-128, 1915 (Bull. 620-F).

described have taken part in at least some of the pre-Cambrian deformation to which the schists have been subjected.

At the base of the sediments is a brick-red detrital rock made up of flakes of schist in an abundant matrix, apparently also composed of minute schist particles with an occasional grain of quartz. The material suggests an indurated oxidized stony soil. It is about 80 feet thick. Overlying it without any sharp plane of demarcation is a conglomerate about 2 feet thick, with rather sparse pebbles of rhyolite and red jasper as much as 5 inches in diameter. The conglomerate in turn grades upward into quartzite. The quartzite is very hard and vitreous and is generally reddish or brown. Much of it is banded parallel with the bedding planes. Little seams or films of specularite on joint planes are rather characteristic.

The first rock to be seen in ascending the ravine is a large body of quartzite folded into a sharp anticline and apparently faulted against shales on the northwest. These shales resemble nothing I had previously seen in Arizona. They are gray-green, weathering yellow, fairly hard, and only moderately fissile, and they effervesce in acid when powdered. Evidently they are somewhat dolomitic. For about 50 feet from their top they alternate with thin beds of quartzite and conglomerate. The conglomerate layers are less than a foot thick and carry pebbles of quartz and red jasper. The strike of the shales where seen is northeast and the dip northwest at 55° in the bottom of the canyon and at 45° near the top of the formation. The stratigraphic base of the shale was not seen, but the apparent total thickness of the beds exposed was very roughly estimated at 1,000 feet.

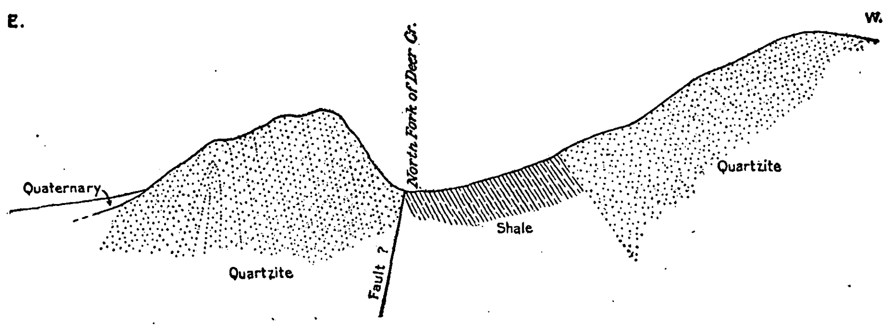


FIGURE 13.—Diagrammatic section on North Fork of Deer Creek, Mazatzal Range, Ariz.

Between many of the beds are thin partings of hard red micaceous shale showing worm casts. These beds were found to continue up the precipitous slope to an altitude of 6,500 feet, but at that point the traverse had to be abandoned. The apparent thickness is at least 1,400 feet, but there is possibly some duplication of folding or faulting. Similar quartzitic beds were observed to continue some hundreds of feet higher, to the crest of the ridge, and quartzite with blocks of coarse grit or fine conglomerate were the only rocks observed in the talus. The pebbles in the conglomerate are as a rule smaller than peas and consist mostly of quartz and red jasper.

Another traverse was made up the North Fork of Deer Creek. The relations there seen are indicated in the rough sketch shown as figure 13. This is not drawn to scale and no attempt was made to measure the thicknesses of the beds.

The shale is overlain, with apparent conformity, by hard brown quartzite in beds generally less than 2 feet in thickness. The dip grows less toward the top of the slope, and at an elevation of 700 feet above the north fork the beds lie in gentle folds with dips of 25° and less. The quartzite beds vary in color, but most are reddish. Layers of small pebbles of quartz and red jasper are fairly abundant.

The same pre-Cambrian quartzites described as occurring in the vicinity of Deer Creek and Mazatzal Peak appear to continue along the crest of the Mazatzal Range to its northern termination at North Peak, the base of the range being schist, granite, and probably other ancient crystalline rocks.

The northernmost point at which the pre-Cambrian sediments have been recognized in this part of Arizona is on Pine Creek, in the vicinity of Natural Bridge, about 8 miles northwest of Payson and 12 miles north of North

Peak. At Natural Bridge, where Pine Creek escapes past an obstructing terrace of travertine, partly by a narrow gorge of wild beauty and partly through a lofty natural tunnel under the calcareous mass, the nearly horizontal Paleozoic limestones and the basal Cambrian sandstone (Tapeats ?) are exposed on the east side of the stream, which has cut through them into the granite. On the west side of the creek is a precipitous slope, 400 to 500 feet high, in which are exposed coarse red granite, overlain by a coarse granitic conglomerate, with bowlders as much as 2 feet in diameter, which in turn is overlain by hard cross-bedded reddish quartzite with layers of conglomerate. These beds dip about north-northwest at an angle estimated at 55°, and are disturbed by faulting. The general relations of the beds at Natural Bridge are diagrammatically indicated in the rough sketch of figure 14. The coarse conglomerate and arkose conglomeratic quartzite on the west side of the creek at Natural Bridge are apparently older than the sandstone and overlying limestone on the east side and are part of a steep ridge that rose above the general level of the granitic surface upon which the basal sandstone (Tapeats ?) accumulated. This ridge can be traced in a north-northeasterly direction from Natural Bridge for about 4 miles, to a point east of Pine, where it passes under the horizontal strata of the plateau. About 2½ miles southeast of Pine, on the road to Payson, the nearly horizontal limestones above the Cambrian sandstone abut unconformably against the slope of this old ridge and locally contain angular fragments of the older quartzite.

While it is difficult to understand the survival of a small sharp ridge as an isolated monadnock on a surface so nearly worn down to a plain as that over which the arenaceous deposits of the Cambrian sea were spread for thousands of square miles, it is still more difficult to account in any other way for this island-like mass of indurated tilted strata surrounded by dissimilar, nearly horizontal, and apparently younger beds. Moreover, these older beds are much more resistant than the granite, and the fact that here and there eminences of hard rock projected above the general level of the vast pre-Tonto floor and were not finally buried until long after the deposition of the Tapeats sandstone is visibly evident in the walls of the Grand Canyon.

Natural Bridge is one of the few places in the region where good accommodations can be had for man and beast, and the locality would well repay more careful study than could be given to it in the course of the hasty reconnaissance made in 1912.

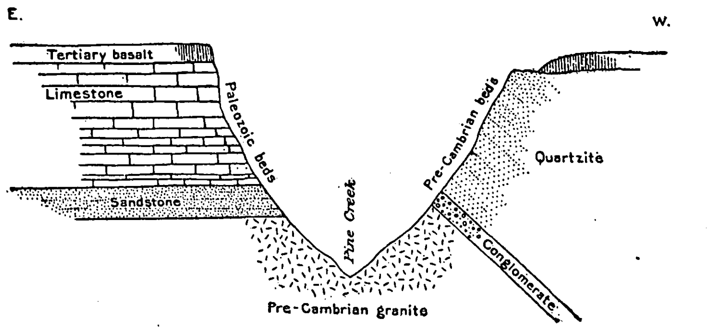


FIGURE 14.—Diagrammatic section across Pine Creek at Natural Bridge, Ariz.

JEROME GEOLOGIC SECTION, WITH NOTES ON STRATIGRAPHY BETWEEN PAYSON AND JEROME.

The geologic column given in Plate XXV as the Jerome section is really a composite, only the part below the Supai formation having been measured at Jerome. The higher beds, however, are well exposed in the escarpment of the plateau a few miles north of the town and along the route from Payson to Camp Verde by way of Fossil Creek. The thicknesses given for the Supai and Coconino formations were obtained by rough aneroid measurements on Fossil Creek and at the head of Pine Creek.

An excellent section of the lower part of the local geologic column is exposed where the road from Payson to Pine crosses East Verde

River. At the base is coarse red granite. Upon this rests horizontally 80 feet of dull red-brown cross-bedded pebbly sandstone. Cliff faces show some irregular horizontal lamination but no distinct divisional planes, and the whole forms a single thick bed. Few of the included pebbles are over an inch in diameter. Overlying the massive bed are thinner-bedded pebbly sandstones grading upward through a thin layer of shale to limestone. The thinner sandstone beds have a thickness of 30 feet, making the total thickness of the basal sandstone 110 feet. As will be shown later, there can be no reasonable doubt of the identity of this sandstone with the Tapeats ("Tonto") sandstone of the Grand Canyon section.

The following section of the overlying limestone was measured by aneroid a short distance west of the river, where the limestone is capped by Tertiary or Quaternary basalt. The numbers correspond to those used in the Jerome section on Plate XXV (p. 136).

Section of limestone near East Verde River.

	Feet.
Basalt.	
8. Rather thin-bedded, in part flaggy light-gray compact limestone, with a few thin beds of sandstone near top	130
7. Pink and gray sandy limestone	50
6. Hard, compact gray limestone in beds 2 to 3 feet thick	50
5. Red shale, with bed of laminated gray quartzite, 2 to 3 feet thick at the top	20
4. Thin-bedded gray limestone. For 25 or 30 feet above the Tapeats sandstone this is flaggy and somewhat sandy. Grades upward into compact, hard light-gray and pink limestone	100
Tapeats sandstone.	350

No fossils were found in these beds, but the limestones are probably, in part at least, Devonian. It is to be noted that the Bright Angel ("Tonto") shale of the Grand Canyon is not represented on the East Verde.

The beds underlying the little alluvial valley at Pine appears to belong to the lower part of the Supai, and higher strata of the same formation crop out as a broad rosy band along the cliffs north and east of the village. As a rule this strip of bright color blends rather indefinitely into the buff tint of the overlying Coconino sandstone, which is the cliffmaker of this part of the plateau edge. An aneroid measurement of the Coconino sandstone at the head of Pine Creek showed that the Coconino is at least 500 feet thick. It is a fine-grained, remarkably homogeneous, and rather soft sandstone, whose constituent quartz grains sparkle brilliantly in the sunlight. The color generally is pale buff to nearly white, but it weathers in more or less rusty tints near the base. Cross-bedding as a rule is more conspicuous than bedding and the rock splits more readily along the oblique laminations than it does parallel with the true bedding.

About 6 miles west of Pine the mail trail between Payson and Camp Verde crosses the canyon of Fossil Creek [1] and affords a fairly good section of the Supai formation, which here consists chiefly of bright-red friable, very fine grained calcareous and gypsiferous sandstones, with a few beds of soft light-gray sandy limestone. One bed of such limestone, about 20 feet thick, is well exposed on the trail about 50 feet below the east rim of the canyon and is regarded as the topmost bed of the Supai. About 800 feet below this bed is a layer of gray limestone conglomerate, about 12 feet thick, with pebbles of limestone as much as 2 inches in diameter. A seam of very impure lignite, reported to be in places 20 inches thick, lies just under this conglomerate and is said by prospectors to be accompanied by some native copper. The barometric readings on this section gave a thickness of about 1,250 feet for the Supai formation, but this is probably a little high, and an estimated thickness of 1,000 feet is used in the Jerome section (Pl. XXV). The Supai beds are locally very soft and generally form steep ruddy slopes under the pale-buff cliffs of the Coconino sandstone. The distinction between the two formations, as seen in cliff faces, is not sharp, as there are some soft reddish beds above the 20-foot gray limestone. Likewise at the base there is some gradation of the red beds into the rather thin bedded gray limestones, presumably Redwall, exposed in the bottom of Fossil Canyon.

Between Fossil Creek and Camp Verde the sedimentary rocks are buried under heavy flows of basalt, with intercalated layers of tuff, which apparently are younger than the extensive lacustrine deposits, consisting of

[1] This creek owes its name to the incrusting action of some copious springs which, after building up a huge terrace of travertine, now issue from the base of the mass, on the edge of the stream.

gypsiferous clays, limestone, gypsum, and salt and probably over 1,000 feet thick, that fill this part of the Verde Valley.

The town of Jerome is west of and about 1,500 feet above Verde River, at the north end of a short range known as the Black Hills. The prospect northeast from Jerome probably surpasses in beauty and geologic interest anything else to be seen in Arizona, except the unrivaled Grand Canyon. From 4 to 6 miles distant, across a belt of relatively low hills whose pale hue proclaims the Redwall limestone, meanders the Verde with its narrow fringe of trees and green fields. Beyond the river, 15 miles away, is the great scarp of the plateau, here thrusting a bold promontory into the valley, there retreating in some shadowy recess where a creek has cut back into the table-land, and glowing along its entire front with the ruddy warmth of the Supai, which shades upward into the creamy tints of the Coconino sandstone and downward into the whiteness of the Redwall. Finally, 50 miles away, beyond the pine forest whose fringe darkens the top of the cliff, the even sky line of the plateau is boldly surmounted by the volcanic mass of the San Francisco Mountains, upon whose crest the snow yields but slowly to the heat of summer. Nor is it necessary to look to these distant peaks for evidence of volcanic activity in recent geologic time. Dark flows of basalt, at various levels, cap parts of the plateau and outlying mesas, much nearer at hand, and only a few miles north of Jerome, Verde River has barely succeeded in cutting through a lava stream that usurped its channel.

The rocks of the Black Hills have undergone some of the deformation which is so characteristic a feature of the mountain region and which gives it a structure and topography so different from that of the plateau, here in plain sight for comparison. The most conspicuous element of the structure near Jerome is a fault that strikes N. 30° W. and dips about 60° NE. The dislocation is of the kind classed as normal, and the throw at Jerome is roughly estimated at about 1,300 feet. The result of the movement has been to elevate the Black Hills relatively to the plateau country, to expose the pre-Cambrian schists southwest of the fault, and incidentally to bring to light the great body of copper ore now worked by the United Verde Copper Co.

Resting upon the schists on the hillside just west of the United Verde mine is the Tapeats sandstone, 75 to 80 feet thick. It is locally a very dark red cross-bedded pebbly sandstone in which the pebbles, for the most part collected into lenticular layers, are rarely over 1 inch and mostly under half an inch in diameter. The dark rusty hue of the sandstone is probably due to ferruginous gossan material, derived from the pre-Cambrian pyritic deposits in the schist.

Conformably above the sandstone are light-yellowish, very compact limestones in beds from 2 to 3 feet thick and containing only obscure traces of fossils. These beds resemble the compact limestones of the lower part of the Martin limestone at Ray. This part of the formation, about 150 feet thick, is overlain by darker-gray limestones, some of which are sandy. Fossils are fairly abundant in these strata, but are as a rule poorly preserved and extremely difficult to collect. About 350 feet above the base of the limestone a light-gray bed about 5 feet thick, sandy in its lower part, but grading upward into a purer and more compact limestone, carries abundant small poorly preserved shells near its base and corals in its upper part. Fossils collected from this bed and those just above it were submitted to Dr. E. M. Kindle, who has identified the following species:

Aulopora sp. undet.
Zaphrentis sp. undet.
Camarotœchia sp. undet.
Spirifer orestes.
Cyrtia cyrtiniformis.
Bellerophon mæra.

Mr. Kindle writes: "These species represent an Upper Devonian fauna of the same general facies as that previously collected by you at various points in Arizona." In other words, it is the fauna of the Martin limestone. The total thickness of the beds provisionally assigned to the Devonian at Jerome is about 500 feet. Of course there is a possibility that the lower compact limestones, from which no fossils were obtained, may be older than Devonian. There are no beds present in the local section, however, that can be referred to the Bright Angel shale.

Above the comparatively thin-bedded and impure Devonian limestone are thicker beds of white limestone, much of which is granular and contains abundant fragments of crinoid stems. This limestone is about 250 feet thick near Jerome. Fossils collected from it were referred to G. H. Girty, who lists the following:

Zaphrentis sp.
Schuchertella aff. S. chemungensis Conrad.
Schizophoria swallowi Hall.
Chonetes illinoisensis Worthen.
Productus burlingtonensis Hall.
Avonia arcuata Hall.
Pustula aff. P. scabricula Martin.
Camarotœchia sp.
Spirifer centronatus Winchell.
Composita humilis Girty?
Euomphalus sp.
Bellerophon sp.

He states that the horizon is clearly lower Mississippian and that the fauna shows close affinities with the Burlington, especially with the lower Burlington. This is unquestionably the Redwall limestone. The two lithologic divisions noted by Lee farther northwest are not apparent at Jerome, unless the beds here grouped with the Devonian correspond to the lower, thin-bedded part of the Redwall as described by Lee.[1] No evidence was obtained at Jerome to indicate that any of the Redwall limestone is as young as the Pennsylvanian. In the Black Hills, the Redwall limestone is overlain by the red Supai beds which in turn are capped by basalt and are not present in full thickness.

Near the mouth of Sycamore Creek, 8 miles north of Jerome, fully 450 feet of limestone is exposed below the Supai. At the base of the Supai is a limestone conglomerate 2 to 3 feet thick in which the pebbles are generally less than 2 inches in diameter. Layers of similar conglomerate also occur a little higher in the formation. At this locality the lower 700 feet of the Supai consists chiefly of fine-grained cross-bedded sandstone in beds less than 6 feet thick, with a smaller proportion of deep red shale. The general color is not brilliant, and some of the sandstone beds incline to a tawny hue. The upper beds of this division of the formation are fairly massive and form an outer bench in the plateau escarpment at this locality. Overlying them and under the Coconino sandstone are apparently softer beds of much brighter red, with an estimated thickness of 200 to 300 feet. As seen through field glasses at a distance of 2 or 3 miles they show conspicuous cross-bedding and appear to grade upward with no sharp break into the Coconino sandstone.

[1] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, pp. 15-16, 1908.

Gilbert [1] has given a section at a locality described as "15 miles southeast of Bill Williams Mountain." This apparently was measured on Sycamore Creek, some miles above its mouth. The section as given indicates the presence of 400 feet of Redwall limestone (base not seen), 600 feet of Supai (that is, 400 feet of "alternating fine-grained limestones and calcareous red and yellow sandstones," overlain by 200 feet of "friable red sandstone"), 700 feet of Coconino sandstone, and 335 feet of Kaibab limestone. overlain by basalt.

GRAND CANYON GEOLOGIC SECTIONS.

The general character and succession of beds in the Grand Canyon are too well known to geologists to require more than very brief description here.

In the section given by Gilbert [2] for the mouth of the Grand Canyon the Tonto group, from the base up, is made to include the "Tonto sandstone" (now the Tapeats sandstone), 80 feet; the "Tonto shale" (now the Bright Angel shale), 600 feet; and the "marbled limestone" (now the Muav limestone [3]) 75 feet. Some uncertainty appears to exist as to the limits of the Muav limestone. Lee,[4] in his section measured a few miles west of the mouth of the Grand Canyon, describes the Tapeats sandstone as overlain by "about 600 feet of yellowish-green arenaceous shale," succeeded by the Redwall. In the Shinumo quadrangle Noble[5] noted 450 to 475 feet of Muav limestone and only 25 to 375 feet of Bright Angel shale. He has separated as the Muav limestone beds that Gilbert and other observers considered to be part of the "Tonto shale," his Muav being the upper calcareous portion of the old "Tonto shale."

[1] Gilbert, G. K., U. S. Geog. Surveys W. 100th Mer. Rept., vol. 3, p. 163, 1875.
[2] Idem, pp. 184, 196.
[3] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Ariz.: U. S. Geol. Survey Bull. 549, p. 64, 1914.
[4] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, p. 15, 1908.
[5] Op. cit., pl. 9.

In the Kanab Valley, northwest of the Shinumo area, according to Walcott,[1] there is 235 feet of "massive mottled limestone with 50 feet of sandstone at base" unconformably below the Devonian and above the "Tonto Primordial." This is probably the Muav limestone. In the portion of the canyon between the Bright Angel and Hance trails the Muav limestone, according to my own observations, is not conspicuously different, either in topographic expression or lithology, from the underlying shaly beds, and although the impure calcareous strata near the top of the Tonto group were not measured, they did not appear to be nearly so thick as was stated by Noble for the Muav limestone in the Shinumo quadrangle. Similarly Frach[2] in his Congress Canyon section gives the Tonto group a thickness of 749 feet, of which the lower 290 feet is sandstone, leaving 459 feet for the generally snuff-colored shaly beds. He mentions the presence of some impure limestone in the upper part of the "upper Tonto," probably the Muav limestone.

The section given for the Kaibab district of the Grand Canyon region in Plate XXV (p. 136) is practically that given by Noble,[3] the latest and probably the most accurate of the published sections of the Grand Canyon strata.

At the base of the stratigraphic column is the great wedge and smaller remnants of Algonkian beds named by Walcott[4] the Unkar and Chuar "terranes" and more recently described in greater detail by Noble.[5] The rocks composing the Unkar and Chuar groups include conglomerates, sandstones, shales, and limestones and are, owing to their variety, not easily characterized in brief. They are essentially fluviatile (deltaic) or shallow-water deposits, prevailingly red in the Unkar group and of more diversity of hue in the Chuar group. Lithologically the rocks of both groups have little resemblance to the lower formations of the Globe-Ray and other sections to the south.

[1] Walcott, C. D., The Permian and other Paleozoic groups of the Kanab Valley, Ariz.: Am. Jour. Sci., 3d ser., vol. 20, p. 222, 1880.

[2] Frech, F., Section in Congress Canyon opposite Point Sublime: 5e Cong. géol. internat., Compt. rend., p. 479, 1893. Congress Canyon is apparently what is known as Red Canyon, through which runs the old Hance trail, and is far east of Point Sublime.

[3] Op. cit., pl. 9.

[4] Walcott, C. D., Algonkian rocks of the Grand Canyon of the Colorado: Jour. Geology, vol. 3, pp. 312-330, 1895. (Gives references to his earlier papers on same subject.)

[5] Noble, L. F., op. cit., pp. 40-53.

The Tapeats sandstone, 285 feet in maximum thickness, is generally a rather coarse cross-bedded sandstone grading here and there into a pebbly grit. Lenticular layers of yellowish well-rounded quartz pebbles, the largest the size of peas, are very common. In contrast with the quartzites of the Algonkian, which commonly show conspicuous vertical jointing, the cliff faces of the Tapeats sandstone are characterized by a nearly horizontal banding, due to alternations of coarse and fine material. The usual color is buff, but in places this shades into dull red or maroon.

The Bright Angel shale, 375 feet thick, consists of fissile shales, for the most part micaceous, associated with thin beds of micaceous sandstone and impure limestones. The prevailing color is greenish yellow, and the formation generally weathers to a smooth slope. It has been carefully described by Noble.[1] Fossils from this formation, including some well-preserved trilobites obtained in 1911 near the Bright Angel trail, have been pronounced Middle Cambrian by Dr. C. D. Walcott.

The Muav limestone, according to Noble,[2] is the predominantly calcareous upper part of the Tonto group and is 475 feet in maximum thickness. Since Bulletin 549 was written he has found fossils in the Muav limestone which, according to Edwin Kirk, of the United States Geological Survey, are of Middle or Upper Cambrian age.[3]

The Devonian Temple Butte limestone, 100 feet in maximum thickness, is in many places absent. Recent work of Mr. Noble, not yet published, supplies many details of its occurrence and of the unconformities between it and the overlying Redwall limestone and the underlying Muav limestone.

The massive Redwall limestone, from 600 to 700 feet thick, is overlain by the relatively thin-bedded red shales and sandstones of the Supai, 1,250 to 1,400 feet thick, followed by cross-bedded Coconino sandstone, 250 to 350 feet thick, and the pale-gray Kaibab limestone, 400 to 600 feet thick, containing Pennsylvanian fossils and extending to the brink of the canyon.

[1] Noble, L. F., op. cit., pp. 62-64.

[2] Idem, pp. 64-65.

[3] Personal communication from L. F. Noble.

CORRELATION.

In the comparison of the ten columnar sections shown in Plate XXV (p. 136) the most obvious stratigraphic plane of reference is the great unconformity at the base of the Cambrian. Another zone useful for correlation is that of the Devonian beds, which, in a north-south belt extending through central Arizona, are made up persistently of limestone, are generally of moderate total thickness compared with the Cambrian and Carboniferous formations, and contain a characteristic fossil fauna, that of the Martin limestone of the Bisbee section. To the east, in the Clifton-Morenci region, the Devonian beds consist chiefly of shale, this probably representing a gradation into the Percha shale of New Mexico. In the Grand Canyon region pre-Redwall erosion has in some places removed the Devonian beds, but they are present in a sufficient number of localities in the canyon, as has been shown by Noble,[1] to establish their lithologic character and their place in the local section. At Jerome the Devonian limestone as represented in the columnar section of Plate XXV is thicker than in the more carefully studied sections to the south. Further examination may show that some of the lower beds provisionally included in the Devonian of the Jerome section belong to an older period.

It is with the correlation of the part of the geologic sections between the Devonian and the unconformity at the base of the Cambrian that the present paper is chiefly concerned. Comparison will first be made of this part of the Globe-Ray section with the corresponding part of the Bisbee section.

The lower parts of these two sections show decided differences. The Globe-Ray section includes the Scanlan conglomerate, the Pioneer shale, the Barnes conglomerate, the Dripping Spring quartzite, the Mescal limestone, and the Troy quartzite, with an aggregate thickness of 1,200 to 1,300 feet. At Bisbee there are the Bolsa quartzite, with some basal conglomerate, overlain by the Abrigo limestone, and the aggegate thickness is about 1,200 feet. In a general way the Bisbee Cambrian section resembles the Grand Canyon section, and it is not difficult to imagine the Bolsa quartzite as equivalent to the Tapeats (formerly the Tonto) sandstone and the Abrigo limestone as equivalent to the Bright Angel shale and Muav limestone (formerly both included in the "Tonto shale"). The probability of this exact equivalence is lessened, however, by the fact that the Bisbee and Grand Canyon sections are separated areally by the Globe-Ray section of a different type.

Fossils, considered by Dr. Charles D. Walcott to be Middle Cambrian, were found in the Abrigo limestone, but the supposed Cambrian portion of the Globe-Ray section has yielded no determinable fossil remains. Correlation by means of paleontology is therefore at present out of the question. Lithologically the Abrigo limestone and the Mescal limestone are in part identical, and as the beds showing this identity are of unusual character and maintain this character over large areas, the conclusion that the Abrigo and Mescal limestone are probably the same appears to be most nearly in accord with the facts. The striking similarity of the peculiar cherty limestone of the Abrigo and Mescal is shown by a comparison of Plates XXVIII and XXX.

If, as is likely, these two limestones are identical, then the Bolsa quartzite is equivalent to the Dripping Spring quartzite or to the Dripping Spring quartzite, Barnes conglomerate, Pioneer shale, and Scanlan conglomerate. In spite of metamorphism which has transformed the Pioneer shale locally to mica schist, the four formations just mentioned are recognizable in the Santa Catalina Range. Evidently, therefore, considerable change takes place within the 50 or 60 miles intervening between the Santa Catalina Range and Tombstone, where the section is of the Bisbee type. If the Abrigo and Mescal limestones are the same, then the Troy quartzite, about 400 feet thick in the Globe-Ray region, is represented at Bisbee by a bed of white quartzite, 8 feet thick, at the top of the Abrigo.[1]

The Clifton section is much like that at Bisbee. The Coronado quartzite is in all probability the same as the Bolsa quartzite. The Longfellow limestone, from Lindgren's descriptions, appears to resemble the Abrigo limestone in many respects and is probably, in part at least, equivalent to it. Fossils obtained from the upper part of the Longfellow

[1] Noble, L. F., paper in preparation for publication.

[1] Ransome, F. L., Geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, p. 32, 1904.

limestone were determined by E. O. Ulrich to be of Ordovician age.[1] As no fossils were found in the upper part of the Abrigo at Bisbee, the occurrence of the Ordovician fossils at Clifton does not preclude correlation of the two limestones.

North of the Globe-Ray region the pre-Devonian units of the Ray section are all recognizable at Roosevelt and in the Sierra Ancha. In the southern part of that range, however, the development of 1,100 feet or more of sandstone above the Mescal limestone makes correlation with the Troy quartzite rather uncertain. This sandstone appears to have the stratigraphic position of the Troy, but differs in lithologic character and is nearly three times as thick as that formation. The significance of this considerable change in the section in so comparatively short a distance as that between Roosevelt and Aztec Peak is not fully understood, and it is doubtful whether the beds of the Sierra Ancha section can ever be traced continuously into those of the Ray-Globe section. The only chance would be by way of the Apache Mountains, and the general structure and topography of the region makes it almost certain that there are gaps of many miles in which the Troy quartzite or its equivalent beds are not exposed or have been removed by erosion.

At the north end of the Sierra Ancha the section below what is supposed to be the Mescal limestone is not readily divisible into the units of the Globe-Ray section. Nevertheless it is believed to be more closely allied to that section than to those north of the Sierra Ancha.

From the north end of the Sierra Ancha to the vicinity of Payson there is a gap of about 15 miles in which the Paleozoic rocks are not present. This interval, as already described on page 157, is occupied by pre-Cambrian crystalline rocks and by the pre-Cambrian quartzites, shales, and conglomerates that are well exposed in the Mazatzal Range. If the Grand Canyon series (Unkar and Chuar) is represented in the Tonto region of Arizona, it is without much doubt to be correlated with these older sedimentary beds and not, as some writers have suggested, with the unconformably overlying Apache group.

The last three sections given in Plate XXV are sections of the practically horizontal strata of the Arizona Plateau and differ materially from those of the more disturbed rocks of the mountain region. This difference is strikingly apparent to one who, after studying the thick quartzitic sandstones of the Sierra Ancha, sees for the first time the sections near Payson, in which a comparatively thin basal sandstone is succeeded by limestones having no resemblance to the Mescal limestone. (See p. 160.) There is apparently little change in the character of the beds from Payson to the vicinity of Jerome, and the basal sandstone is, without much doubt, the Tapeats sandstone ("Tonto" sandstone) of the Grand Canyon section. The Bright Angel shale and Muav limestone, however, have not been identified at Jerome or at any locality southeast of that town.

The plateau sections differ also from those of the mountain region south of Payson in the development of the Carboniferous strata. In central and southern Arizona the Carboniferous is represented by great thicknesses of gray limestone that is not, as a rule, easily separable into Mississippian and Pennsylvanian portions. In the plateau sections there is a great development of sandstones and shales, and the Carboniferous deposits are divisible into the Redwall limestone, the Supai formation (red sandstones and shales), the Coconino sandstone, and the Kaibab limestone, named in ascending order.

Gilbert's Canyon Creek section, while distinctly of the plateau type, indicates considerable change in character east of Payson. It shows an increase in the thickness of the Cambrian sandstone and the absence of the Devonian beds through unconformity. No unconformity was noticed between the Devonian and Carboniferous at Jerome, but the study given to this section was too hasty to warrant the assertion that none is present.

The observations presented in this paper indicate that in Cambrian time a land barrier existed in the region now adjacent to Tonto Basin, between the depositional basin of central and southern Arizona and that now corresponding to the Arizona Plateau, or at least to that part of the plateau between Payson and the Grand Canyon. It follows that while the whole Apache group and its stratigraphic equivalents in eastern and southern Arizona were probably deposited at about the same time as the beds of the Tonto group, the beds of the two groups were probably never continuous within the Tonto region of Arizona. It can not

[1] U. S. Geol. Survey Geol. Atlas, Clifton folio (No. 129), p. 4, 1905.

be said that any particular sandstone or quartzite of the Apache group is identical with the Tapeats sandstone.

Although the evidence from fossils is lacking, it appears to be fairly well established that the entire Apache group is Cambrian, or possibly in part younger, and, so far as can be seen over a wide region, is conformably overlain by the Devonian, while in the northern parts of the Mazatzal Range and Sierra Ancha the Paleozoic beds overlie with conspicuous unconformity a series of shales, quartzites, and conglomerates which is probably equivalent to the Grand Canyon series.

The marked difference in the Carboniferous sections of the two geographic provinces in north-central Arizona suggests that the natural barrier supposed to exist in Cambrian time may have persisted in some form, possibly as a submarine ridge, throughout the Paleozoic era.

THE PLIOCENE CITRONELLE FORMATION OF THE GULF COASTAL PLAIN.

By George Charlton Matson.

PRESENT INVESTIGATION.

In the spring of 1910 the writer, working under the direction of T. Wayland Vaughan, geologist in charge of Coastal Plain investigations, undertook a study of the later Tertiary formations of the Gulf Coastal Plain. According to the plans outlined before the work was begun, the beds that had formerly been grouped under the names Lafayette formation and Grand Gulf formation were to be studied with a view to their possible separation into more satisfactory stratigraphic units that might be correlated with other formations which, on the basis of their fossils, had been assigned to their proper positions in the geologic time scale. The original plan included a study of the post-Vicksburgian Tertiary deposits from western Florida to Mississippi River and correlations with formations previously recognized in Florida, southern Alabama, and Louisiana. This plan was subsequently modified to extend the investigation as far west as Sabine River. The field work was interrupted and the office work was delayed by calls for geologic work in other areas, so that the preparation of the reports could not be begun until the spring of 1914.

SCOPE OF THIS REPORT.

In this paper it is proposed to discuss the general character and relations of beds of Pliocene age and to leave for subsequent publications the details of lithologic character and distribution of the Pliocene beds recognized. Although not abundantly fossiliferous, these Pliocene deposits contain some fossil plants, and at two localities—near Lamberts, north of Mobile, and at Red Bluff, on Perdido Bay—it was possible to obtain collections adequate for correlation. The fossil plants from these places are described elsewhere in this report by Mr. Berry, who also discusses their geologic age.

EARLY INVESTIGATIONS.

The area considered in this report has been studied by a number of geologists, though few of them had adequate opportunity to examine the formations in detail. The major portion of the time at their command was naturally devoted to the fossiliferous formations, and the nonfossiliferous beds were assigned to groups that by some investigators were probably regarded as separable into formations provided enough time could be given to their study. The result of this method of classification was to group together beds differing in age and having very extensive geographic distribution. The beds of each of these groups were composed of materials of similar lithologic character that appeared to be nonfossiliferous. The lithologic character of the materials naturally depended on two factors—the source of the material and the processes to which the sediments had been subjected since their removal from their original position. The sediments of the Coastal Plain were transported to approximately their present position by streams that existed when deposition began, and in any broad drainage basin the material for the different formations from the older to the younger was derived either wholly or in part from the older lands to the north, even though shore currents shifted some sediments from one place to another and eroded and redeposited materials along the strand line. In some places, however, no terrigenous deposits were laid down and the formations are made up either wholly or in part of organic or chemically precipitated material.

As the detrital deposits came from a common source, they vary only in accordance with the character of the changes to which they have been subjected since they were eroded from the older land surface. The processes of weathering that have affected the formations of the

Coastal Plain since their deposition have been comparatively uniform, and for this reason the sediments of different ages in the Coastal Plain that are now available for examination are very similar. In the later part of Tertiary time, except in Florida, there was a general absence of strictly marine conditions, and organic deposits of that age are either thin or entirely lacking. The Coastal Plain formations in general are composed of clays and sands derived from the older land, transported to their present position by the streams and in places by marine currents and waves and subjected since their deposition to similar processes of weathering. As a result the deposits are so similar that they can be divided into distinct formations only by laborious investigation with careful attention to detail. Such studies were beyond the reach of early investigators, both because of lack of time and because of lack of funds for their prosecution.

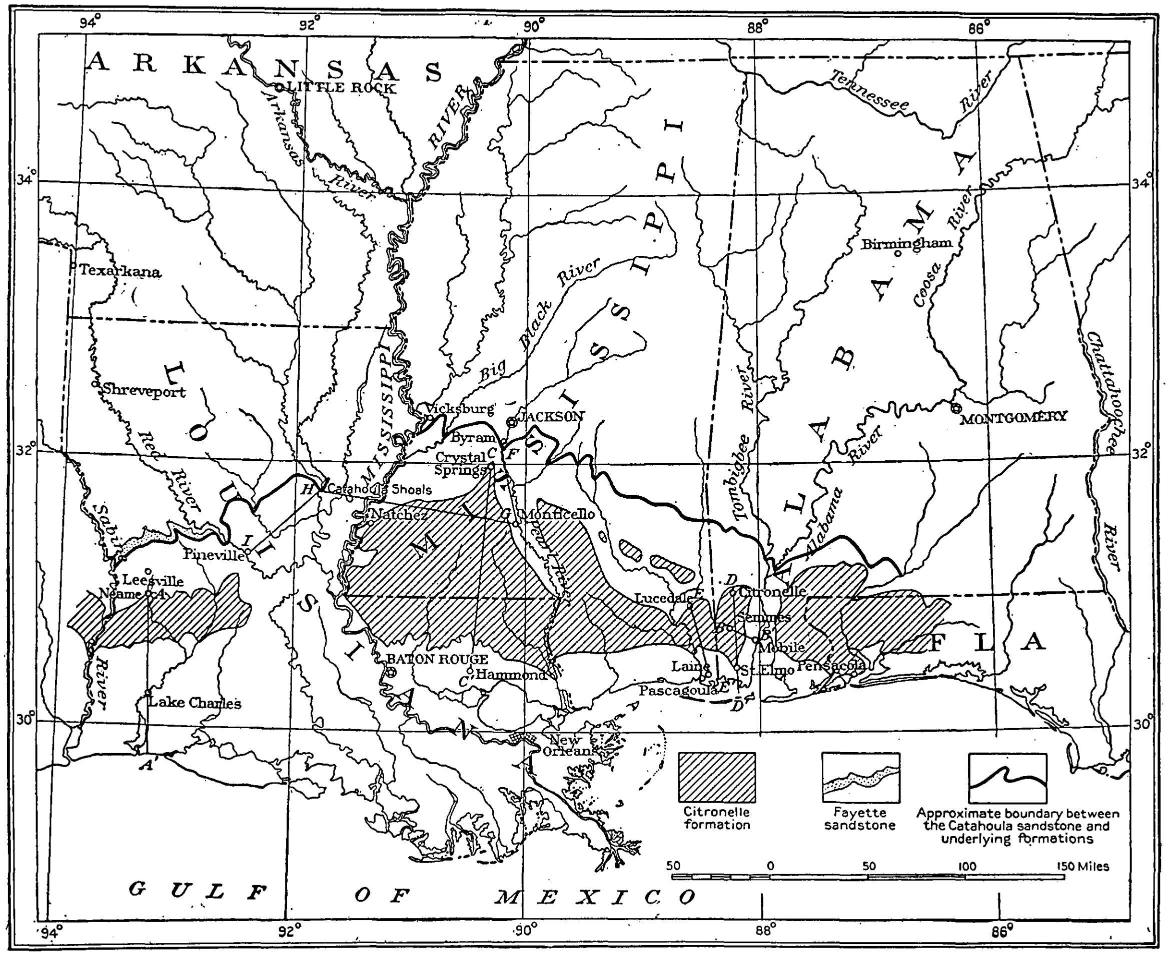


FIGURE 15.—Map of Louisiana, Mississippi, and Alabama showing approximately areas covered by Citronelle formation and Fayette sandstone and boundary between Catahoula sandstone and underlying formations. Sections along lines *A-A'*, *B-B'*, *C-C'*, *D-D'*, *E-E'* are given in Plate XXXII; sections along lines *F-G*, *G-H*, and *H-I* in figure 20 (p. 219).

FORMATION NAME.

The name Citronelle formation is applied to sediments of Pliocene age, chiefly nonmarine, that occur near the seaward margin of the Gulf Coastal Plain, extending from a short distance east of the western boundary of Florida westward to Texas. (See fig. 15.) Citronelle, a town on the Mobile & Ohio Railroad, in the northern part of Mobile County, Ala., was chosen as the type locality because of the excellent exposures of the formation in its vicinity, especially to the north along the railroad for a distance of 3 or 4 miles. The best collection of fossils was obtained from a clay bed a few miles south of the type locality, near a station called Lamberts, where a flora sufficiently well preserved to permit correlation of the beds with the Pliocene was found.

SYNONYMY.

The Citronelle formation is the equivalent of a portion of the deposits formerly classified as "Drift," "Orange sand," and "Lafayette." The name can not be regarded as a synonym for any of the older terms because in all the earlier descriptions the old names were made to include not only the Citronelle formation, but overlying alluvial and colluvial sands and gravels and extensive areas of sand and gravel lying farther inland and belonging to a number of different terranes. In addition, the earlier applications of the old names were such as to include beds of Pleistocene age, forming a fringe between the Pliocene beds and the coast and extending into the river valleys. The development and use of the different names will be mentioned briefly in discussing the earlier publications.

The Lafayette of some writers may have included not only the Citronelle but portions of the older formations, together with the alluvial material forming the flood plains and terraces along the streams and the colluvial sands, gravels, and clays distributed on the slopes. In some places portions of the unweathered Miocene and Oligocene beds were called Lafayette, though in most localities only the weathered portions were included. The use of the term "Lafayette" was so elastic that exposures on the valley slopes might all have been included in the formation, even though the outcrops of the older beds were unweathered, or the unaltered beds might have been called "Grand Gulf," the weathered deposits "Lafayette," and the relations of the deposits explained by assuming that the contact between the "Lafayette" and "Grand Gulf" was irregular.

PREVIOUS DESCRIPTIONS.

One of the earliest reports on the geology of the Gulf Coastal Plain contains a description of what is called "Diluvium or northern drift."[1] The areal distribution of the materials described indicates that the gravels of glacial origin bordering the Mississippi are included under that term, together with the alluvial deposits on some of the smaller streams and also, it is thought, some of the beds of Pliocene age. The siliceous pebbles mentioned in this report, especially the fossiliferous cherts, are similar to those found in some of the gravels of the Citronelle formation, though this can hardly be regarded as conclusive evidence for correlating these deposits with the Citronelle, because such materials may be expected in other formations derived from the same sources. The occurrence of the porphyry mentioned by Wailes would probably be limited to gravels of glacial origin, because it is unlikely that such materials would be derived from the sedimentary formations occurring in the drainage basin of the Mississippi and its tributaries.

[1] Wailes, B. L. C., Report on the agriculture and geology of Mississippi, pp. 245-253, Mississippi Geol. Survey, 1854.

In a report by Harper,[1] published three years after that of Wailes, the name "Orange sand" is used to designate materials that had been called "Diluvium" in the earlier publication. This name, which was taken from a report by Safford,[2] continued in use for many years, though it was necessary to redefine it in order to harmonize the application by different writers. It is clear from the following quotation that Harper [3] intended to apply this term to a part of the deposits herein named Citronelle formation:

> This cover is thickest where the Eocene meets the Miocene. It decreases southward towards the seacoast and the State of Louisiana; but nevertheless hills of the Orange sand, with the characteristic pebble stratum, are found here and there even very near the seacoast.

The application of the terms Eocene and Miocene by this writer is so unusual and so different from the present usage that for the benefit of those who may not have access to Harper's geologic map, it seems advisable to say that he included in the Eocene the entire area south of the outcrop of the Jackson formation. It is in this area that his Orange sand includes the Citronelle formation. A discussion of the other beds classed as Orange sand by Harper may be omitted because they lie outside of the area included in this report.

The reports cited above were based on brief reconnaissances in which observations were made at widely separated localities. Although some of the later investigations were of similar character, a tendency toward more detailed study is shown in the character of the reports. The deposits included in the Citronelle forma-

[1] Harper, L., Preliminary report on the geology and agriculture of the State of Mississippi, p. 162, Mississippi Geol. Survey, 1857.
[2] Safford, J. M., Geological reconnaissance of Tennessee, pp. 148, 162, 1856.
[3] Harper, L., op. cit., p. 162.

tion were first systematically discussed on the basis of extensive field investigations by Hilgard,[1] who included beds belonging to the Citronelle formation in the "Orange sand." He said:

> But the formation which gives character to the surface conformation of the State—whose presence is the rule, and whose absence the exception requiring special mention; which forms the main body of most ridges and, to a very great extent, their surface also—is that which has been very appropriately designated by Prof Safford, the State geologist of Tennessee, as the Orange sand formation.

The term "Orange sand," as used by Hilgard, includes some of the deposits herein named Citronelle formation and also portions of older and younger deposits correlated with them on the basis of lithologic character.

In a discussion of the "Orange sand" Hopkins[2] correlated some of the materials in Louisiana with the Orange sand of Hilgard. In his section across the State the name "Prairie diluvium" includes the beds now called the Citronelle formation, as well as both older and younger beds. A subsequent report by Hopkins[3] contains a more comprehensive discussion of the "drift," in which he included a large amount of material varying in age from the oldest beds exposed in Louisiana to the Pleistocene. Among these beds are the deposits here named Citronelle formation, which Hopkins mentioned in connection with the distribution of the drift in some of the parishes south of the outcrop of the beds later designated Catahoula sandstone. The geologic map accompanying Hopkins's report shows the area occupied by the Citronelle formation as covered by what he calls "drift." A third publication by this author discussed the "drift" in more detail, giving special attention to its constitution and origin.[4] The identifiable fossils occurring in pebbles are listed, but unfortunately some of the localities where these pebbles were collected were not given, though Hopkins stated the age of the geologic formations that supplied these pebbles and the possible geographic distribution of the localities from which they are derived. The report contains some speculation as to the means of transportation of these pebbles to their present positions.

[1] Hilgard, E. W., Report on the geology and agriculture of the State of Mississippi, pp. 4-29, Mississippi Geol. Survey, 1860.

[2] Hopkins, F. V., Louisiana Geol. Survey First Ann. Rept., for 1869 (included in the annual report of the Louisiana State Seminary of Learning and Military Academy), p. 78, 1870.

[3] Hopkins, F. V., Louisiana Geol. Survey Second Ann. Rept., pp. 21-26, 1871.

[4] Hopkins, F. V., Louisiana Geol. Survey Third Ann. Rept. (included in annual report of D. F. Boyd, superintendent Louisiana State University, for 1871), pp. 190-203, 1872.

After the publication of the papers cited there was a revision of the nomenclature because of the confusion resulting from the differences of usage in different areas. The necessity for this revision was emphasized when McGee[1] correlated his Appomattox formation with "at least a part of the Orange sand of Hilgard and other southern geologists."

In 1891 the name "Orange sand" was replaced by "Lafayette formation," the type locality for the new name being in Lafayette County, Miss.,[2] where, according to Berry,[3] the "Orange sand" is of Eocene (Wilcox) age. This change was made at a conference in which Hilgard, McGee, LeConte, and Loughridge participated, and the decision reached by them was subsequently indorsed by Safford.[4] McGee was the first geologist to apply the term Lafayette to deposits distributed over the entire area of the Coastal Plain and extending across the edges of the older formations between Washington and the Rio Grande.[5] Although he regarded his Lafayette as somewhat more restricted than Hilgard's Orange sand, it is clear that he included in the Lafayette the beds now known as the Citronelle formation. This is shown by numerous references to the localities where this formation is at the surface, by the maps accompanying the report, and by numerous diagrams showing the relations of the formations exposed on the Gulf Coastal Plain. The accompanying sections (figs. 16 and 17) illustrate the relations of the "Lafayette" to older and to younger formations, and if the thickened portion of the "Lafayette" as represented in these sections is separated from a portion of the thin layer on the upland it will represent approximately the Citronelle formation. As the present report does not deal with the major portion of the deposits coating the surface of the upland, it has seemed best to omit them from the discussion.

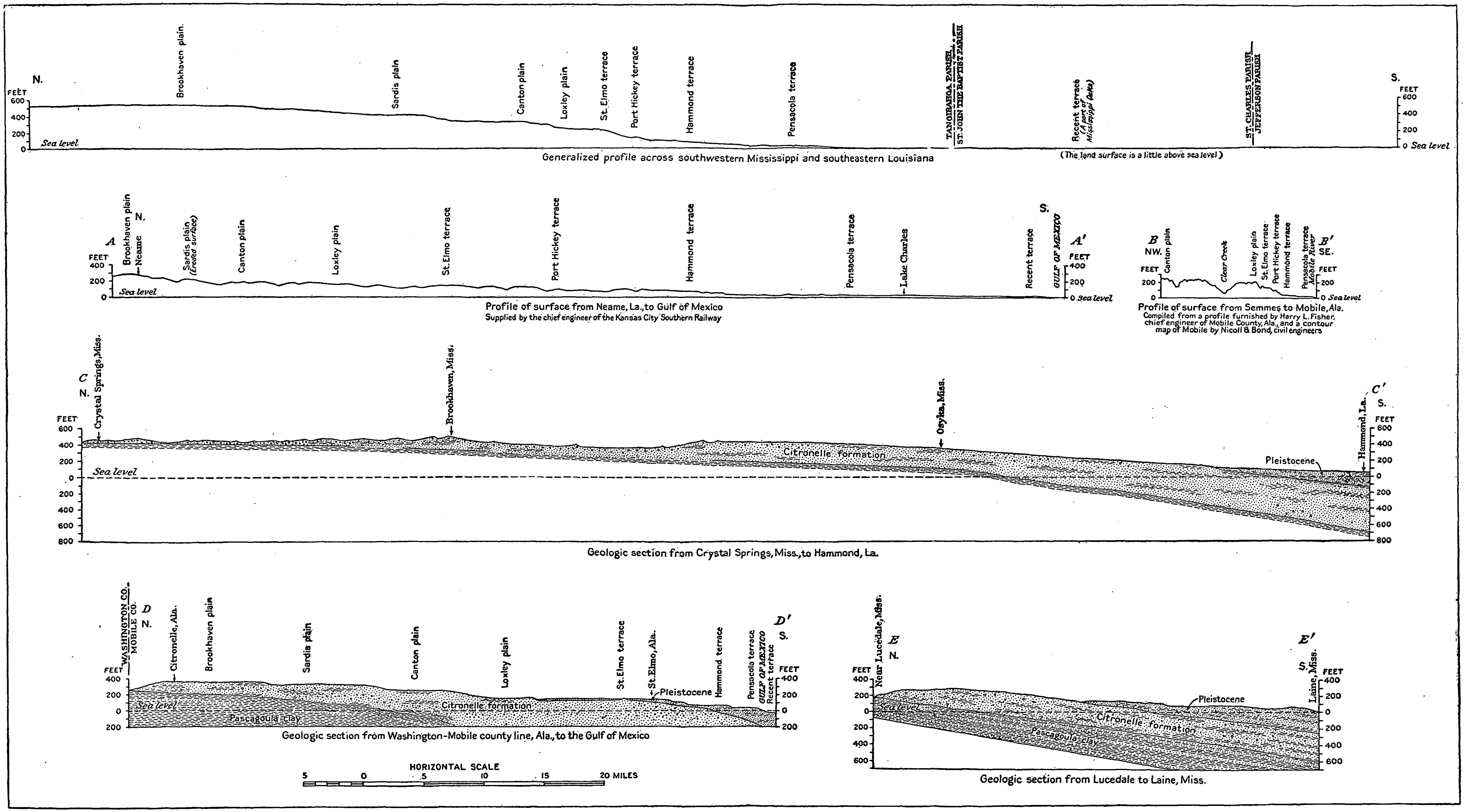
[1] McGee, W J, Three formations of the middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. 35, p. 330, 1888.

[2] Hilgard, E. W., Orange sand, Lagrange, and Appomattox: Am. Geologist, vol. 8, pp. 129-131, 1891.

[3] Berry, E. W., The Lafayette formation: Jour. Geology, vol. 19, pp. 249-256, 1911.

[4] Hilgard, E. W., op. cit., p. 131.

[5] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 430-501, 1891.



SECTIONS OF THE CITRONELLE FORMATION AND PROFILES OF THE TERRACES.

After the appearance of the report by McGee the name "Lafayette" was adopted by writers on Coastal Plain geology and soon came into general use, in an area extending from Maryland to Rio Grande. The present report, however, is restricted to the area from western Florida to eastern Texas and does not deal with the Atlantic border of the Coastal Plain though some of the superficial materials on the older Tertiary and the Cretaceous formations are not included in the Citronelle. In dealing with the thin coatings of weathered sand or clay resting on the older beds it is in many places difficult to obtain enough physiographic evidence to warrant correlations, because of the lack of topographic maps.

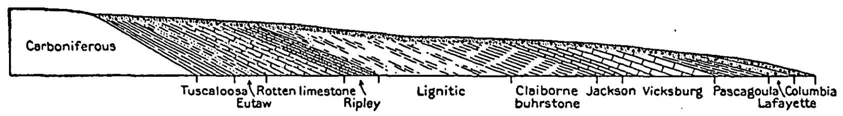


FIGURE 16.—Section through the Coastal Plain in western Alabama; generalized in part from sections constructed and described by E. A. Smith and L. C. Johnson. (After McGee.)

or with the major portion of the region west of Sabine River.

Clendennin [1] discussed the "Lafayette formation" as developed in Louisiana, and the geographic distribution as he described it is much the same as that of the Citronelle, but this author followed McGee by including older materials also.

A paper by Dall and Stanley-Brown [1] gives details of a number of sections along Apalachicola River in Florida and notes on exposures at Bainbridge and Macon in Georgia. In this paper the upper member of each of the sections on Apalachicola River is called Lafayette, and these beds are correlated with the exposures farther north. If any of these exposures are to

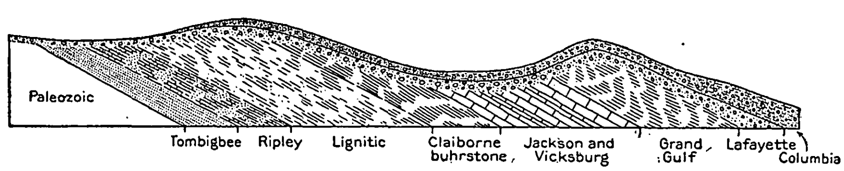


FIGURE 17.—Section through the Coastal Plain in the Mississippi embayment; generalized in part from sections constructed and described by E. W. Hilgard and L. C. Johnson. (After McGee.)

The "Lafayette" in Alabama was described by Smith,[2] who summarized its distribution as follows:

> While the materials of the Lafayette formation are to be found as a superficial covering over the entire Coastal Plain of the State; that is, over all the Tertiary and Cretaceous strata, lapping in places even far over upon the edges of the Carboniferous and other Paleozoic terranes—it is only in the two Gulf-bordering counties, Mobile and Baldwin, that we find it forming one of the structural units, intercalated between the Biloxi and Second Bottom deposits above and the fossiliferous clayey sands of the Pascagoula horizon below.

The portion of the "Lafayette" which this author called a structural unit belongs to the Citronelle formation, and some portions of what lies above the older formations to the north may be outliers of this formation, be classed with the Citronelle formation it is the upper part of the section at Alum Bluff, though from their conformity with the clays resting on the Miocene the fine sands and clays forming the upper portion of the bluff are believed to be older than Pliocene.

The Citronelle formation in Louisiana is included in the beds called "Lafayette formation" by Harris,[2] who made special reference to the occurrence of this formation on the east side of Mississippi River and in the "Florida parishes." A large part of the information in this report seems to have been gleaned from the earlier publications by former geologists of Louisiana and from the comprehensive paper by McGee. The information concerning the territory covered by this formation west of the

[1] Clendennin, W. W., The Florida Parishes of east Louisiana and the bluff, prairie, and hill lands of southwest Louisiana: Louisiana Geol. Survey, pt. 3, pp. 187-192, 1892.

[2] Smith, E. A., Johnson, L. C., and Langdon, D. W., jr., Report on the geology of the Coastal Plain of Alabama, p. 66, Alabama Geol. Survey, 1894.

[1] Dall, W. H., and Stanley-Brown, Joseph, Cenozoic geology along the Apalachicola River: Geol. Soc. America Bull., vol. 5, pp. 169-170, 1894.

[2] Harris, G. D., Geology and agriculture of Louisiana: Louisiana Geol. Survey, pt. 5, pp. 99-107, 1899.

Mississippi is somewhat less complete than that about the area east of the river, but special mention is made of the gravel pit in the southern part of Rapides Parish. Another paper by the same author was published in one of the subsequent reports of the Louisiana Geological Survey.[1] This paper is devoted very largely to a discussion of the theories of the origin of the "Lafayette formation," with some mention of the distribution of the beds referred to it. The localities noted in the area covered by the Citronelle formation are Neame, where the beds are over 275 feet above sea level; Sulphur, where the same deposits are reported to occur in a well extending to a depth of more than 400 feet below sea level; and Morgan City, where they extend to a depth of more than 500 feet. The relations of these deposits are shown graphically in a diagram of the country from a point north of Jackson, Miss., southward through Tangipahoa, Amite, and Hammond to the Gulf.

The reports by Crider[2] afford little additional information concerning the Citronelle deposits. This author included in the "Lafayette formation" the beds in the southern part of Mississippi belonging to the Citronelle formation and stated that they were reported to attain a thickness of over 200 feet.

Veatch[3] dealt in considerable detail with the "Lafayette formation" in Louisiana, including in this formation beds belonging to the Citronelle, as shown by his diagram and by his statement of the detailed distribution of the formation. He said:

> South of the Catahoula and Fleming formations these sands and gravels form the surface for miles and then pass southward beneath the more recent clays of the Quaternary, forming there the water-bearing beds which furnish a portion of the waters used in the irrigation of that region.

It is possible that in addition to the beds described in this quotation some of the deposits classed as Lafayette lying north of the area described are outliers of the Citronelle formation.

[1] Harris, G. D., Geology and agriculture of Louisiana: Louisiana Geol. Survey, pt. 6, pp. 32-36, 1902.

[2] Crider, A. F., and Johnson, L. C., Summary of the underground-water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 159, pp. 12-13, 1906. Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 44-46, 1906.

[3] Veatch, A. C., Geology and underground water resources of northern Louisiana: Louisiana Geol. Survey Bull. 4, pp. 43-45, 1906.

In 1907 Smith[1] discussed the "Lafayette formation," which he made to include the area underlain by the Citronelle formation. The term "Lafayette formation" as used in this report is not synonymous with Citronelle formation, but some of the beds covering a portion of the "Grand Gulf" and lying south of the northern margin of that formation may belong to the Citronelle.

Matson and Clapp[2] discuss the "Lafayette formation" in Florida in a general way. The Citronelle formation comprises only a minor part of the area assigned to the "Lafayette" in Florida and is not included in any of the detailed sections given. In this report the name "Lafayette" is used for the weathered portions of deposits of Oligocene, Miocene, and Pliocene age and for surface deposits of various ages.

STRATIGRAPHIC RELATIONS.

The Citronelle formation rests upon the Pascagoula clay (Miocene) and overlaps the Oligocene formations. Wherever the contact with the underlying formations has been observed it is marked by an unconformity, the older formations having been eroded before the deposition of the Citronelle formation. (See Pl. XXXII.) The seaward margin of the Citronelle formation is overlain by beds of Pleistocene age, and contacts between the Pliocene and younger beds can be seen at many places. They show a marked unconformity, the Citronelle formation having been eroded and the materials derived from it having been incorporated with materials from other sources to form the deposits of Pleistocene age. (See Pl. XXXIII.) The unconformity may also be inferred from the fact that the Pleistocene deposits form terraces along the seaward margin of the Citronelle formation and extend into the valleys of the major streams, reaching entirely across the Citronelle and resting upon the still older formations. The relation of the Citronelle to the other formations of the Gulf Coastal Plain is shown in the accompanying table.

The Citronelle formation differs from both the older and the younger formations in being

[1] Smith, E. A., The underground water resources of Alabama, pp. 24-25, 302-316, Alabama Geol. Survey, 1907.

[2] Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida, with special reference to the stratigraphy: Florida Geol. Survey Second Ann. Rept., pp. 141-145, 1909.

Pleistocene and Tertiary formations of the Gulf Coastal Plain.

Age.	Eastern Texas.	Louisiana.	Mississippi.	Alabama.	Alabama.	Florida. Western.	Florida. Peninsular.
Pleistocene.	Pensacola terrace. Hammond terrace. Port Hickey terrace. St. Elmo terrace.	Pensacola terrace. Hammond terrace. Port Hickey terrace. St. Elmo terrace.	Pensacola terrace. Hammond terrace. Port Hickey terrace. St. Elmo terrace.	Pensacola terrace. Hammond terrace. Port Hickey terrace. St. Elmo terrace.		Pensacola terrace. Tsala Apopka terrace. Newberry terrace.	
Unconformity							
Pliocene.	Citronelle formation. Nonmarine chiefly, including high-level terraces. Yellow and red sands and clay, locally gray where unweathered. Gravel near the landward margin. Thickness, 50–250 feet.	Citronelle formation. Nonmarine chiefly, including high-level terraces. Yellow and red sands and clays, locally gray where unweathered. Much gravel near the landward margin, especially in the valley of Red River. Thickness, 50–400 feet.	Citronelle formation. Nonmarine chiefly, including high-level terraces. Yellow and red sands and clays, locally gray where unweathered. Much gravel near the landward margin and in the valleys of the principal streams. Thickness, 50–400 feet.	Citronelle formation. Nonmarine chiefly, including high-level terraces, marine fossiliferous equivalents in wells. Yellow and red sands and clays; locally gray where unweathered. Gravel near the landward margins contains fossil plants. Thickness, 50–340 feet.		Citronelle formation. Nonmarine chiefly, including high-level terraces; marine fossiliferous equivalents in wells. Yellow and red sands and clays, some gravel. Thickness, 50–150 feet.	Caloosahatchie and Nashua marls. Marine.
Unconformity							
Miocene.	Pascagoula clay. Marine in part. Blue, green, and gray clay, locally calcareous and fossiliferous. Some large calcareous concretions and many small nodules. Some layers of sand and sandstone. Thickness, 250–300 feet.	Pascagoula clay. Marine in part. Blue, green, and gray clays, locally calcareous and fossiliferous. Some layers of sand; locally a sandstone near the top. Many nodules of calcium carbonate in some layers of the clay. Thickness, 250–450 feet.	Pascagoula clay. Marine in part. Blue and gray clays and sands; some thin beds of sandstone; locally gravels and conglomerates at the base. Fossiliferous marls in places and some clays with nodules of calcium carbonate. Thickness, 50–400 feet.	Pascagoula clay. Marine in part. Blue and gray clays and sands. Thickness, 250 feet.		Choctawhatchee marl. Marine.	Jacksonville formation. Marine.
Unconformity							
Oligocene.	Hattiesburg clay. Nonmarine. Blue and gray clay; some layers calcareous. Thin layers of sand and sandstone. Thickness, 300–350 feet.	Hattiesburg clay. Nonmarine. Blue and gray clay; some beds calcareous. Thin layers of sand and sandstone. Thickness, 300–350 feet.	Hattiesburg clay. Nonmarine. Blue and gray clay with thin beds of sand and sandstone. Thickness, 350–450 feet.	Hattiesburg clay. Nonmarine.[a] Blue and gray clay with thin beds of sand and sandstone. Thickness, 300 feet.	Alum Bluff formation. Marine.	Apalachicola group: Alum Bluff formation. Marine.	
Oligocene.	Catahoula sandstone. Nonmarine. Gray sands, sandstones, fine conglomerates, quartzites, and clays. Thickness, about 475 feet.	Catahoula sandstone. Nonmarine. Gray sands, sandstones, fine conglomerates, quartzites, and clays. Thickness, 600–800 feet.	Catahoula sandstone. Gray sands, sandstones, fine conglomerates, quartzites, and green clays. Thickness, 200–550 feet.	Catahoula sandstone. Gray sands, sandstones and green clay. Thickness (maximum), about 200 feet.	Chattahoochee formation. Marine.	Apalachicola group: Chattahoochee formation. Marine.	
Oligocene.		Vicksburg limestone.	Vicksburg limestone. Marine.			Marianna limestone. Marine.	
Eocene.	Fayette sandstone. Marine. Gray sands, sandstones, quartzites, and dark, calcareous clays. Thickness, 100–160 feet.						
Eocene.	Jackson formation. Marine. Fossiliferous marls, clays, and some thin beds of sandstone. Traceable into typical Jackson of Mississippi. Thickness, 50 feet.	Jackson formation. Marine. Gray sands, sandstones, and dark calcareous clays. Thickness, 100–160 feet.	Jackson formation. Marine.	St. Stephens limestone. Marine.		Ocala limestone.[b] Marine.	

[a] Redefined.

[b] According to C. W. Cooke.

predominantly sandy, with many lenses and scattered pebbles of chert gravel. To understand fully the application of the name it is necessary to know the mode of deposition of the formation. After the Miocene strata had been laid down the Coastal Plain was eroded into broad, shallow valleys having approximately the same positions as those of the present streams. These valleys were filled by the deposition of Pliocene alluvial sands and gravels, and near the coast the deposits were extended across the interstream areas. This filling formed a broad plain, which was later partly eroded, while at the same time the margin of the formation was pushed farther seaward and three successively lower plains were built, their sediments resting on the older deposits. The original deposit formed a seaward-sloping plain, and each successive addition formed a new plain, which was represented also in the stream valleys. (See Pl. XXXII.) Some portions of the deposits were doubtless reworked by the waves, especially in the interstream areas, and this accounts for the more complete rounding of the pebbles in portions of the seaward areas of the formation than in the stream valleys and the development of flat plains with shallow ponds in the interstream areas. The closing stage of the deposition of the successive plains is marked by the fine sandy silts laid down at flood stages while the streams were eroding their beds to lower levels. The deposition was pushed far seaward in some places, as shown by sands with Pliocene fossils at Pensacola and Mobile and by a leaf-bearing clay at Red Bluff, on Perdido Bay, Ala.

The sediments included in the Citronelle formation have sometimes been referred to the Pleistocene because of their physiographic resemblance to the terraced deposits of Pleistocene age. They differ from the Pleistocene deposits of the Gulf coast, however, by being more sandy and containing more gravel. The evidence of their greater age is shown by their mature dissection, which in general exceeds that of the coast Pleistocene and glacial deposits, and by the weathered condition of the pebbles, many of which are composed of chert so completely decomposed as to break or even crumble easily in the hand. The Pliocene age is further shown by the presence of the Pliocene fossil plants, those at Red Bluff showing that the deposition was originally extended some distance beyond the southern margin of the general area shown in figure 15 (p. 168), and that the Pleistocene material was later deposited upon the eroded surface of the Citronelle. The line between the Pliocene and Pleistocene plains is drawn between the 150-foot and 200-foot terraces. The Pleistocene age of the plains at lower levels is shown by their slight dissection and by the presence of crystalline pebbles in the fluviatile portion of the 150-foot terrace at Natchez, Miss.

The 150-foot terrace rises gradually landward to 170 feet or more, and its representatives in the river valleys are still higher, attaining elevations of somewhat more than 200 feet a short distance from the coast. Deposits of this terrace contain the pebbles of crystalline rocks at Natchez—the Natchez formation.

The Pliocene plains are more eroded than the Pleistocene plains and when compared in the same area they may be distinguished by this difference. The Pliocene material was considerably eroded before the formation of the uppermost Pleistocene terrace, and relatively wide valleys were developed even on some of the small streams. The formation of the Pleistocene terraces was begun by a submergence that affected the drainage some distance from the coast and resulted in the formation of flat, swampy areas along most of the streams. These readjustments in drainage conditions are still marked by swamps in many of the small stream valleys in southern Alabama, Mississippi, Louisiana, and southeastern Texas, the flat-bottomed valleys being overgrown by swamp vegetation through which the streams meander in very poorly defined channels.

LITHOLOGY.

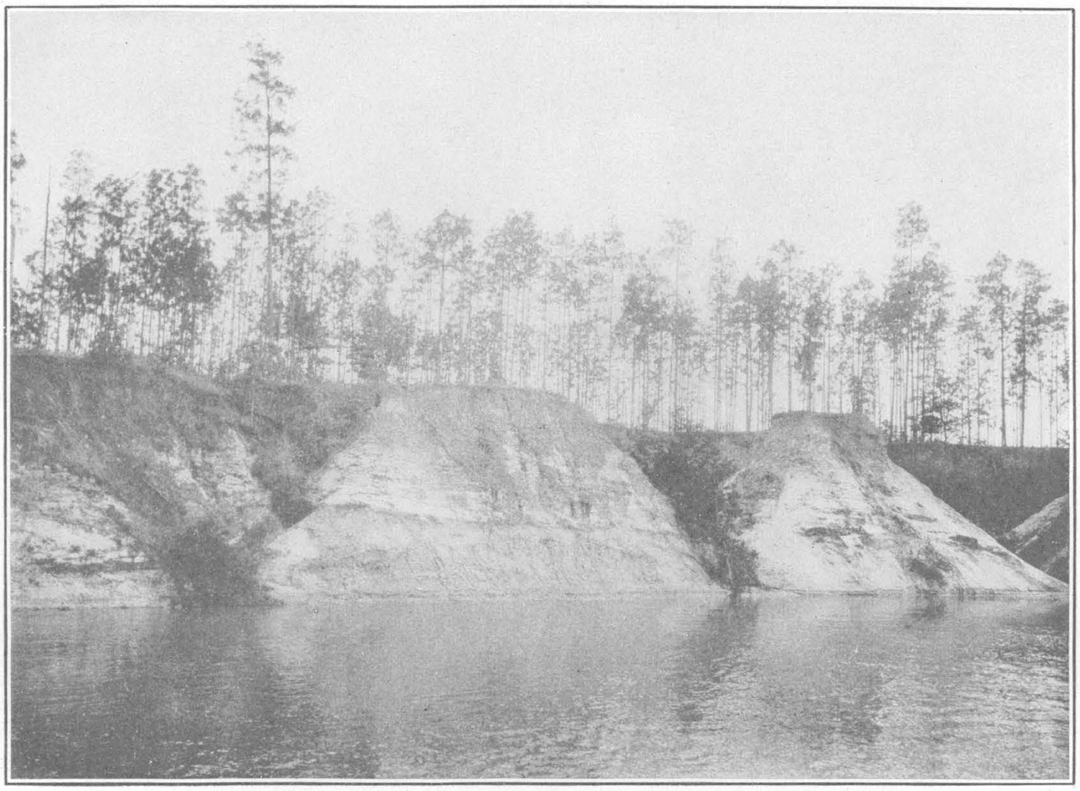
The Citronelle formation is predominantly sandy but contains varying amounts of clay in the form of thin layers or lenses. (See Pl. XXXIV.) The relative proportion of materials of different kinds varies from place to place, and in any one section it varies from top to bottom, though in general sand is everywhere abundant (see Pls. XXXV and XXXVI), and at many places there is some gravel. The proportion of sand is greatest near the base, and the formation contains more sandy material in the vicinity of the principal drainage lines than in the interstream spaces. There is also a larger percentage of sand and gravel near the landward than the seaward margin of the formation (see Pls. XXXVII and XXXVIII), though in making comparisons it is necessary to consider large masses and to choose localities bearing about the same relations to the principal lines of drainage, because more sand and gravel will be found in the vicinity of large streams near the coast than on some of the interstream spaces farther inland.

The sands of the Citronelle formation are sufficiently rounded to indicate that they have been subjected to extensive attrition. The pebbles vary greatly in degree of rounding; many of them are much waterworn and resemble pebbles found on the beach, others are only slightly rounded, and still others are subangular. The sand is predominantly quartz, and the pebbles in the Mississippi embayment are mostly chert, with a somewhat smaller percentage of crystalline quartz and quartzite. Many of the chert pebbles contain cavities lined with chalcedony in the form of agates or geodes, and a large number of them are fossiliferous, containing fragments of corals, crinoid stem, and other organic remains such as are common in the Paleozoic limestones and chert. In Alabama there are many pebbles of quartz, with a subordinate percentage of quartzite, but in some places chert pebbles are numerous. In western Louisiana the pebbles are mostly quartz with some admixture of chert.

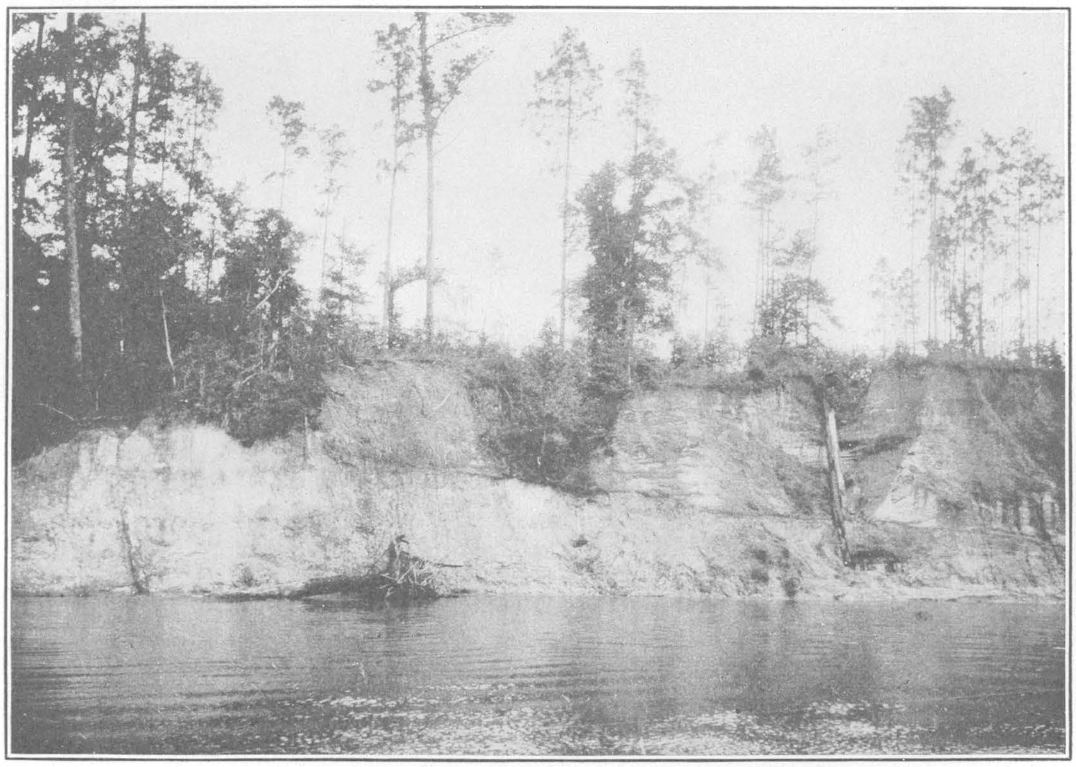
Certain peculiarities in the distribution of materials in the Citronelle formation are worthy of mention. In Mississippi the outliers are in general composed of coarse subangular chert gravel, with a varying percentage of small, well-rounded quartz pebbles. In Louisiana and Alabama quartz gravel is common. The coarse pebbles have in a measure the same composition and evidently came from a common source, and the same is true of the fine pebbles. The coarse subangular fragments are mostly chert and have been subjected to fluviatile wear with very little subsequent rounding by waves, but many of the finer, well-rounded pebbles are quartz and have doubtless been shaped by prolonged subaqueous erosion. Probably the subangular material was brought directly from its original source, and the fine, well-rounded material was subjected to wave erosion by being deposited in some one or more of the older formations of the Coastal Plain, from which it was obtained by Pliocene streams. This conclusion seems warranted because the gravel is a poorly assorted aggregate of material of all sizes from sand to pebbles an inch or two in diameter. (See Pls. XXXIX, XL, and XLI.) If the gravel had been subjected to wave action during Pliocene time it would have been assorted, and it is therefore inferred that the perfect rounding of the small pebbles was accomplished by wave action during earlier geologic periods.

The clays vary greatly in character, some of the beds being relatively pure and others distinctly sandy. On the whole the sandy clays predominate, and in many places thin layers of sand are found in the clay beds.

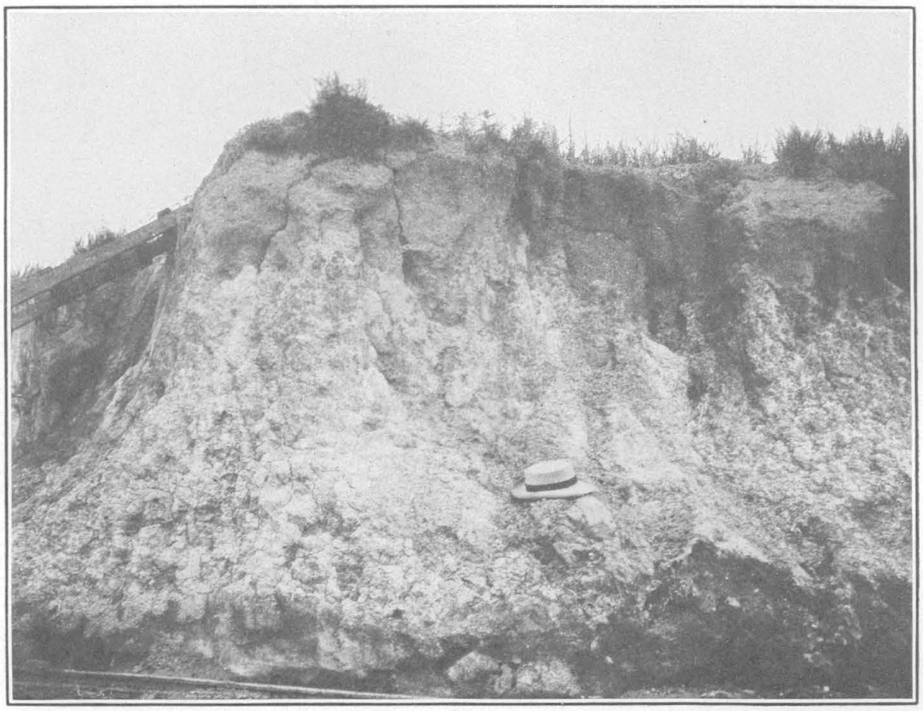
The Citronelle formation has a very wide range in color. Doubtless when fresh some of the materials included in the formation were either blue or gray with small percentages of red and yellow, but nearly all the exposures available for observation at the present time have been subjected to so much weathering that the original colors have been partly or wholly obliterated. The sands in most of the sections are either orange or red, though near the surface some of them are yellow. This predominance of the orange and red colors on weathered surfaces led to the designation of the materials in this formation, either wholly or in part, as "Orange sand." The clays vary in color according to the degree of weathering to which they have been subjected, beds that have been buried to sufficient depth to protect them from the oxidizing effect of the atmosphere or surface water being either pale blue or gray. Where the oxidation has been slight they are mottled, the first change producing spots or blotches of a light-red or peculiar purplish color. As the process of weathering continues the purple color disappears and a deep-red color predominates, and still further weathering changes the red color to pale yellow. The iron in the clay, which presumably causes the coloring, changes during the process of oxidation to hydrous oxide, and on complete weathering of the clay to a yellow color the iron becomes more or less aggregated into nodules of varying sizes. Somewhat similar aggregations of iron hydroxide occur in the sands in the form of concretions and geodes,



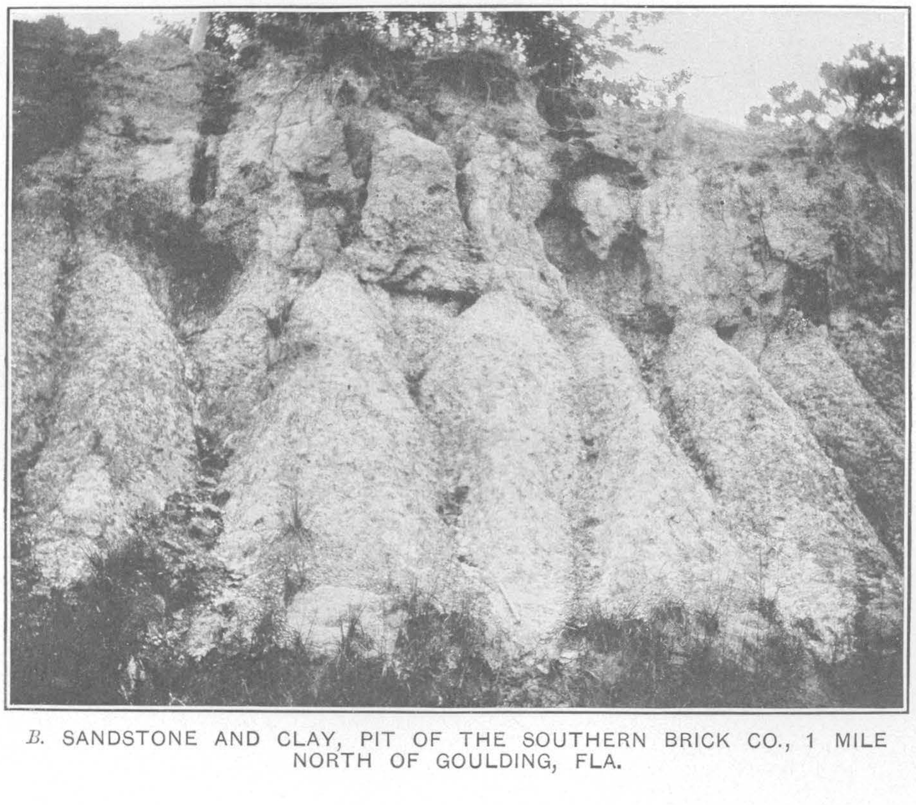
A. CITRONELLE FORMATION (?) OVERLAIN BY PLEISTOCENE SAND AND LOAM ON THE WEST BANK OF ESCAMBIA RIVER SOUTH OF MOLINO, FLA.



B. ANOTHER VIEW NEAR THE SAME LOCALITY, SHOWING UNCONFORMABLE CONTACT.



A. CLAY PIT OF THE SOUTHERN BRICK CO., 1 MILE NORTH OF GOULDING, FLA.



B. SANDSTONE AND CLAY, PIT OF THE SOUTHERN BRICK CO., 1 MILE NORTH OF GOULDING, FLA.

or as shells inclosing cores of clay. In other places the iron accumulates in the form of plates cementing thin layers of sand or as a filling for more or less definite cracks that cross the strata at high angles. Where the iron hydroxide is disseminated among the sand grains or pebbles it transforms the bed into a sandstone or conglomerate. This cementation apparently takes place near the surface and as a rule does not extend for any great distance along a bed, so that in most places the sandstone and conglomerate are in the form of blocks of varying sizes. (See Pl. XXXVIII, *A*.) The irregularity in size and shape of these blocks usually prevents them from being utilized in construction, even where they are firmly cemented, but south of Citronelle, at the 28-mile siding on the Mobile & Ohio Railroad, a hard sandstone belonging to this formation has been quarried to a depth of over 5 feet, and the rock obtained at this locality has been used in the construction of a church.

The texture of the formation in any particular locality depends entirely on the arrangement and relative percentages of the different kinds of materials. In general, the sands form more or less continuous beds containing lenses of pebbles or clay that in some places have considerable horizontal extent and in others are limited to only a few feet. Many clay lenses are only a few feet to a few rods in extent, though in places they interlock with other lenses lying above and below them, and in that way present the appearance of a continuous bed, unless it is possible to examine the section in detail. In the sands cross-bedding and cross lamination are the rule rather than the exception, the layers of clay and pebbles in many places being inclined at high angles. Smooth, even bedding is comparatively rare except in the clay lenses.

In this formation, as in many others, pebbles of clay are common, occurring at many stratigraphic horizons and having a wide geographic distribution. Most of them are more or less perfectly rounded balls of clay embedded in sand in such a way as to form a lenticular clay conglomerate. In places there are more or less rounded blocks of clay in which the original lamination is still preserved. Here and there this lamination coincides in direction with that of the sands, but as a rule it differs. Doubtless many of the pebbles were eroded from the subjacent clay by the currents that transported the sand. Some of the pebbles and probably most of the angular fragments were derived from the undercutting of small cliffs developed by waves or currents. (See Pl. XLII.) This explanation for blocks of clay embedded in sand was first suggested by T. Wayland Vaughan[1] to account for similar clay fragments found in some of the sands of the Wilcox formation, but it is also applicable to such clay fragments in the Citronelle formation.

STRUCTURE.

In the Citronelle formation the arrangement of the sediments in lenticular beds makes it impossible to determine the structure by observations on the elevation of beds (see Pls. XXXIX, *A*, and XL, *B*) except at a few localities where the conditions are unusually favorable. The prevalence of cross lamination and cross-bedding renders determinations of dip with a clinometer valueless because the inclinations observed may not agree in direction with the dip of the beds, and they may vary in direction or be in opposite directions in a single section. Under such unfavorable conditions the recognition of local structural features is everywhere difficult and in most places impossible.

The inclination of the base of the formation can be measured in many places, especially near the landward margin. The results of such measurements show that the dip is not uniform, and in addition to irregularities resulting from deposition on an uneven surface there is a general increase in the rate of inclination of the base of the formation toward the coast. These facts are well shown by the section across southwestern Mississippi and eastern Louisiana, where the contact of the Citronelle with the older formations descends at an average rate of a little less than 6 feet to the mile from a point 6 miles north of Wesson to Osyka, Miss., and at a much higher rate from Osyka, Miss., to Hammond, La. (See Pl. XXXII.) Other sections show steeper inclinations, but they are based on less accurate and less detailed information. The base of the Citronelle formation near the coast is drawn at the transition

[1] Unpublished notes.

from sands, sandy clays, and gravel to finer-grained sediments, chiefly clays, containing characteristic fossils of the Pascagoula clay, and the correlations are probably approximately correct, though there may be errors of a few feet in the position of the contact because of slight inaccuracies in the well logs used for the purpose of obtaining measurements of depths to the base of the Citronelle formation. Where the computations of the rate of dip of the base of the formation are made on a line several miles in length, the amount of error in the rate per mile is minimized.

The actual dip of any portion of the formation may be less than the inclination of the base, because deposition probably began near the coast and was gradually extended inland. This is suggested by the fact that the coarse gravels that form outliers along the landward margin of the formation rest on finer deposits belonging to the Citronelle farther south. For example, the coarse gravel rests on the Pascagoula clay near Wesson, but at Brookhaven it overlies about 130 feet of red sand with interbedded clay that is included in the Citronelle. The gravels are covered near Summit by still younger sediments that are more argillaceous than those below.

Near the coast the upper portion of the formation was laid down on the seaward slope of the earlier deposits, and in this portion the actual dip is probably greater than the dip of the base of the formation. In the absence of reliable data to use in computing the true dip, however, it seems best to give the inclination of the base. The exact dip of the base of the formation is not easy to determine, because near the coast there are no exposures that reach the contact with the Pascagoula formation and it is difficult to interpret the information supplied by some of the logs of wells. Such computations as have been made give discordant results that are probably not entirely due to the incomplete information but are partly explained by local variations in the rate of dip.

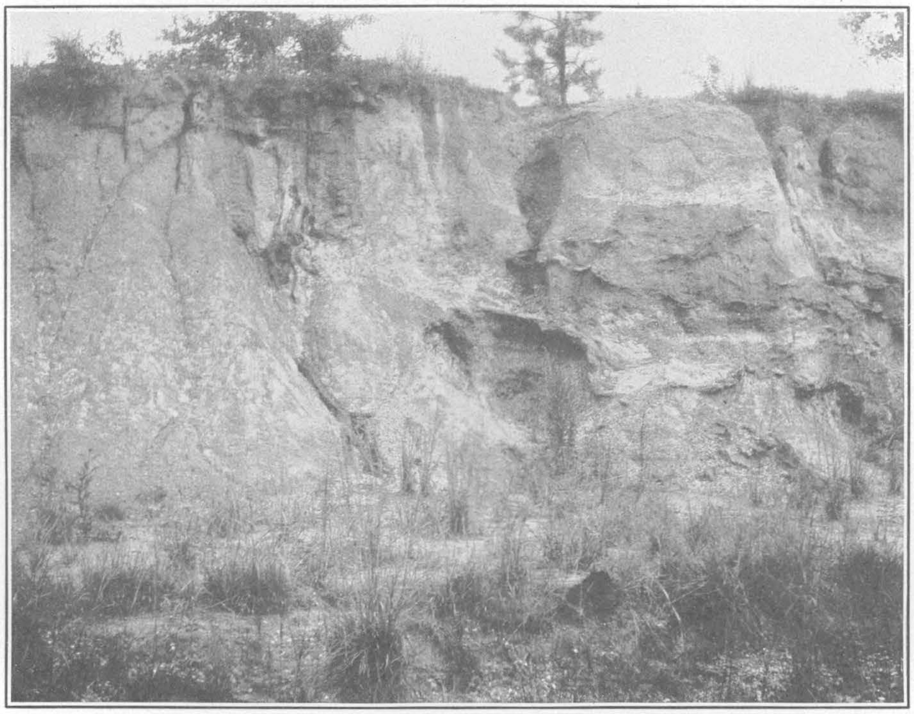
In the northern part of Mobile County, Ala., the base of the Citronelle formation is about 240 feet above sea level, and at Citronelle, 4 miles south of the county line, the contact with the underlying Pascagoula clay is at 220 feet above sea level, giving an average inclination of about 5 feet to the mile. From Citronelle southward to Semmes the contact descends from 220 feet above sea level to 92 feet below sea level, or at the rate of about 16 feet to the mile.

At Laine, Miss., where the surface is about 10 feet above sea level, characteristic fossils of the Pascagoula formation were obtained from the De Lamorton well at a depth of 615 feet (?), and the base of the gravel beds was reached at 605 feet. This well is 53 miles S. 28° W. from the place in Mobile County, Ala., where the elevation of the base of the formation was determined, indicating a dip of nearly 16 feet to the mile, provided the gravel reached in the well is at the base of the Citronelle formation; but as the gravel may be somewhat above the contact the dip thus determined should be regarded as the minimum inclination of the base of the formation rather than the exact amount.

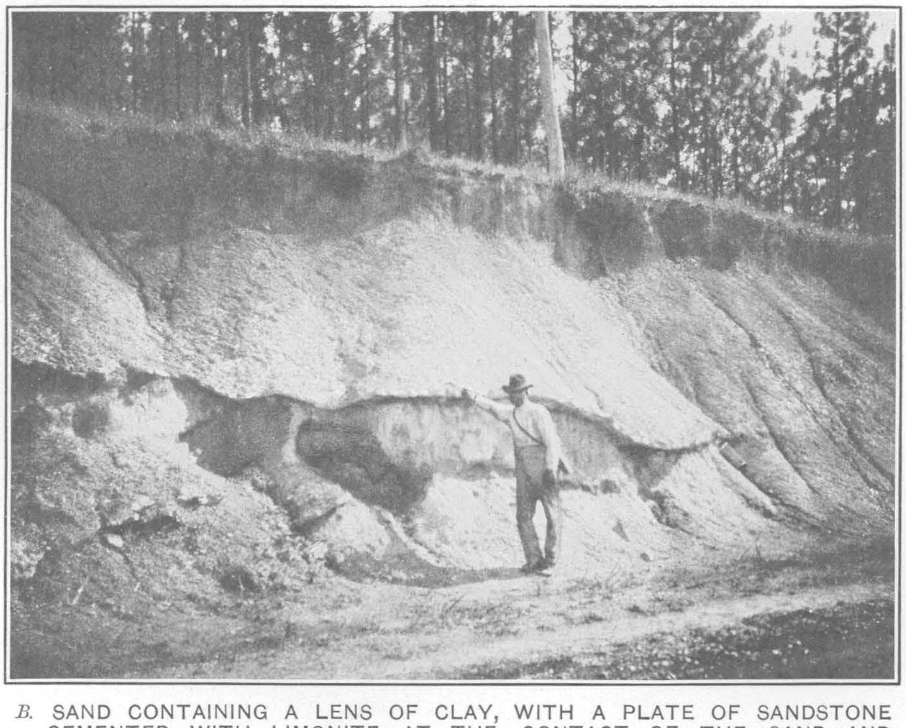
Near Maxie the base of the Citronelle formation is about 215 feet above sea level, and at Bond, 6 miles S. 20° E., a well reached the contact of this formation with the clays of the Pascagoula at an elevation of 115 feet. The steep dip between these two points, nearly 17 feet to the mile, is explained by the fact that the formation was deposited on an uneven surface. Computations of the rate of dip between Maxie and Laine give about 14 feet to the mile, and the direction is about S. 45° E. At Fontainebleau,[1] about 20 feet above sea level, fossils belonging to the Pascagoula clay were obtained in a well at a depth of 500 feet. These fossils probably came from beds near the top of the Pascagoula, and they show that the dip of the Citronelle formation between Maxie and Fontainebleau is between 14 and 15 feet to the mile in a direction S. 35° E.

In western Mississippi measurements of the dip of the Citronelle formation have been made farther inland than in eastern Mississippi and in Alabama. (See Pl. XXXII.) Six miles north of Wesson the base of the formation is 435 feet above sea level, and just east of Brookhaven it is 330 feet above sea level. Here the contact of the Citronelle with the older formations descends about 115 feet in 15 miles, or at the rate of nearly 8 feet to the mile. From Brookhaven to Osyka the contact descends from 330 to 100

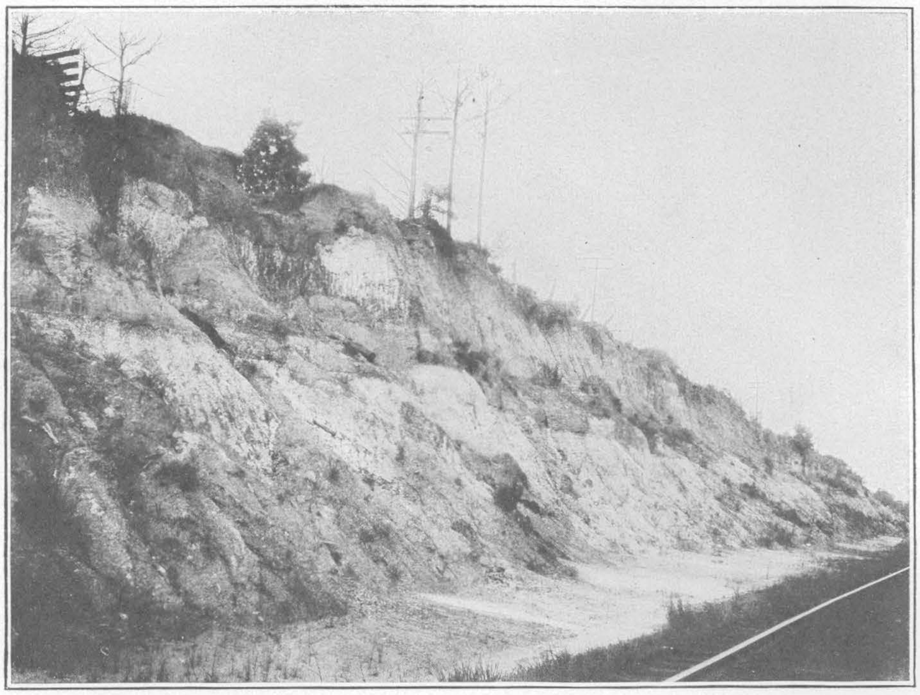
[1] Crider, A. F., and Johnson, L. C., Summary of the underground water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 159, p. 32, 1906.



A. SANDS AND SANDY CLAYS WITH PLATES OF LIMONITE-CEMENTED SANDSTONE, NORTHERN ESCAMBIA COUNTY, FLA.



B. SAND CONTAINING A LENS OF CLAY, WITH A PLATE OF SANDSTONE CEMENTED WITH LIMONITE AT THE CONTACT OF THE SAND AND CLAY, NORTHERN ESCAMBIA COUNTY, FLA.



A. SAND AND CLAY, FLOMATON, ALA.

B. SAND AND GRAVEL, FLOMATON, ALA.

feet above sea level, or 230 feet in about 39 miles, which is at the rate of 6 feet to the mile. From Osyka southward the dip is difficult to determine because of meager information, but it apparently becomes steeper, amounting to approximately 810 feet between Osyka and Hammond, a distance of 35 miles, which would be at an average rate of about 23 feet to the mile. These determinations are all made along a line extending nearly north and south.

In Louisiana many wells have been drilled south of the margin of the Citronelle formation, but the materials penetrated in most of them are not described in the records with sufficient exactness to permit correlations. Between Centerville, Miss., and Bass, La., the rate of dip of the base of the formation is about 19 feet to the mile, and it must increase rapidly toward the south, as is shown by the great thickness of the overlying Pleistocene deposits at New Orleans. Between Osyka, Miss., and Bass, La., the rate of descent is about 10 feet to the mile and the direction about southwest. This is less than the slope from Centerville to Bass and probably indicates that there was a delta in the Mississippi Valley during this epoch rather than an embayment. West of the Mississippi few data that can be used in computing the dips of the formation have been obtained. About a mile north of the Jennings oil field, where the strata are undisturbed and the surface is only about 25 feet above sea level, Miocene fossils were found at a depth of 1,960 feet.[1] The base of the Citronelle formation near Woodworth, about 70 miles north of the Jennings oil field, is approximately 140 feet above sea level. This would give a dip of nearly 30 feet to the mile, provided the fauna found near Jennings came from the top of the Pascagoula clay. This dip represents a maximum, and the actual rate of descent between the two points is probably not so great.

The figures given in the foregoing discussion should be regarded as only approximate measures of the rate of inclination of the base of the formation. The general dip of the deposits beneath the Pleistocene along the southern margin of the formation is shown in Plate XXXII and amounts to less than 20 feet to the mile. The general dip is toward the south, though there are doubtless many local variations in direction. Dips determined from the elevations of the bases of outliers and from logs of wells drilled where the Citronelle formation is at the surface are much lower than 20 feet to the mile, and the rate is variable because the formation was deposited on a surface that was uneven and had a steep slope near the Pliocene strand line. This steep slope accounts for the fact that near the coast the dip becomes steeper, probably exceeding 20 feet to the mile. In the vicinity of New Orleans the original slope near the Pliocene strand line may have been increased by subsidence during Pleistocene time, as shown by the great thickness of Pleistocene beds (2,443 feet) overlying the Tertiary formations.[1]

The thickness of the Pleistocene beds at Fort Morgan, Ala., suggests a steep descent of the Pliocene Citronelle formation. The log of the well at that place, shown in Plate XLIII, in pocket, was made from a series of samples of drillings, and the subjoined list of fossils was furnished by Mr. Dall.

	Depth (feet).
Fragments of echinoderms and two Recent shells, *Donax variabilis* Say and *Paramya subovata* Conrad	30–32
Dentalium acus Dall, *Nassa acuta* Say, Ervilia sp. junior, Ostrea, and echinoid fragments, all Recent	30–40
Recent shells, *Mulinia lateralis* Say, *Donax variabilis* Say, *Arca transversa* Say, etc.	32–87
Recent species, *Abra æqualis* Say, *Arca transversa* Say, *Strigilla carnaria* Linné, *Mulinia lateralis* Say, Leda, Pecten, and Dolium fragments	100–112
Strigilla carnaria Linné, Recent	169–175
Ostrea fragments	175–256
Recent species, Ervilia cf. *E. nitens* Montgomery, *Phacoides crenella* Dall, *Mulinia lateralis* Say, Diplodonta sp., *Modiolus demissus* fragments, Cadulus and Cymatium fragments	217–321
Fragments of Phacoides, Mulinia, Ostrea, and Marginella sp.; probably Recent	322–337
Divaricella cf. *D. dentata* Wood, fragments; Mulinia cf. *M. lateralis* Say; Cadulus fragments; and Phacoides sp., young; probably all Recent	523–570
Nassa acuta Say, upper Miocene to Recent	1,076–1,089
Ostrea fragments	1,089–1,121
Conus pealei Green, Recent	1,244–1,290
Mulinia lateralis Say, Recent to Miocene	1,290–1,330
Chione sp., fragments	1,350–1,370
Ostrea fragments, Anachis cf. *A. avara* Say, and a fragment of Turritella sp	1,378–1,573

The material above 1,290 feet is nearly all Quaternary; that below may possibly be Pliocene.

[1] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, p. 58, 1910.

[1] Harris, G. D., op. cit., p. 170.

This well is 35 miles S. 35° E. from St. Elmo, where the Pliocene reaches an elevation of 130 feet above sea level. The surface of the Citronelle formation descends about 1,220 feet between these two points, or at the rate of more than 35 feet to the mile, but the original inclination may have been much less, because although the Pliocene has been eroded at both localities the amount of post-Pliocene erosion was greater at Fort Morgan, which is near the axis of Mobile Bay.

Near Pensacola the available information suggests a somewhat lower dip for the top of the Citronelle formation. At Pine Orchard, nearly 7½ miles north of Pensacola, the top of the formation is about 160 feet above sea level, and about 4½ miles south of Pensacola the shells obtained at a depth of 256 to 276 feet below sea level were tentatively referred to the Pliocene by Mr. Dall. This indicates a maximum dip of 416 feet in a distance of about 12 miles, or at the rate of about 35 feet to the mile, approximately toward the south.

From the foregoing statements it seems evident that there is a rapid increase in the rate of inclination of the top of the Pliocene near the coast at Pensacola and Mobile and north of New Orleans, and similar conditions doubtless prevail along the entire shore line. This apparent steeper dip at Pensacola and Mobile is, however, partly explained by the fact that in the wells cited the seaward equivalent of the Citronelle formation may have been reached some distance above the level of the fossil-bearing beds. Still, even after liberal allowances have been made for inaccuracies due to this cause, it is obvious that the top of the Citronelle formation must originally have had a steep seaward slope near the coast.

THICKNESS.

The thickness of the Citronelle formation is variable, ranging from a few feet near the landward margin of the formation to several hundred feet near the coast. Exact determination of the thickness near the coast is difficult because it is necessary to rely in part on logs of wells for data, and the information obtained from this source is not entirely satisfactory. The uncertainty is increased by the fact that the overlying Pleistocene beds consist of sands and clays resembling those belonging to the Citronelle formation.

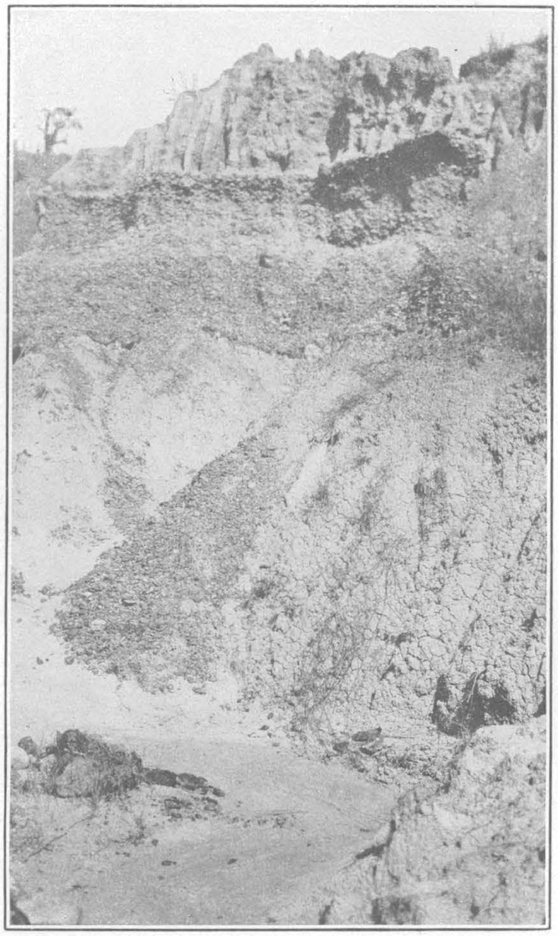
In southern Alabama the Citronelle formation forms a high upland reaching nearly 350 feet above sea level, and in the adjacent valleys the older formations are not exposed in the valleys where the elevation is less than 100 feet. Thus the formation may have a thickness of more than 250 feet. The log of a well drilled about 12 miles west of Mobile shows sand and gravel to a depth of 245 feet and an additional thickness of pink sand and clay amounting to 95 feet. This gives a minimum thickness of 245 feet and a maximum of 340 feet.

In Mississippi the thickness of the outliers of the Citronelle formation as a rule does not exceed 20 to 30 feet. At Bond a well penetrated 90 feet of sands and gravel belonging to this formation before encountering the underlying Pascagoula. The De Lamorton well at Laine passed through sand containing some tree trunks at a depth of 141 to 153 feet. The materials beneath this sand are described as sand, shale, and gumbo to a depth of 615 feet, where Pascagoula fossils were obtained. These materials included a gravel bed with its base at 605 feet, and if this is at the base of the Citronelle the thickness of the formation at that place may be as great as 452 feet. At Fontainebleau the Pascagoula clay was reached at a depth of 500 feet,[1] and as the Pleistocene beds are probably as thick there as at Laine, the thickness of the Citronelle formation at Fontainebleau is estimated to be about 350 feet.

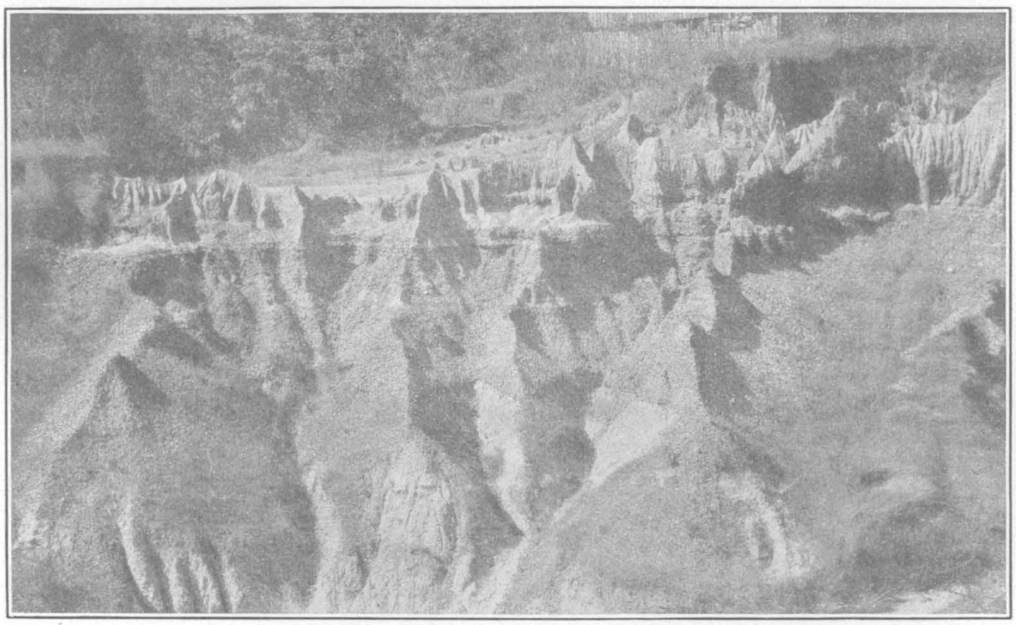
A well at Osyka passed through 150 feet of sand and gravel belonging to the Citronelle formation, and the formation has an additional thickness of about 50 feet beneath the upland. Farther south, at Hammond, the thickness may amount to several hundred feet, though the formation is not readily separable from the Pleistocene, and accurate determination of thickness is impossible. Near Brookhaven the Citronelle formation has a thickness of about 130 feet, but it thins to a few feet within a distance of 20 to 30 miles farther north.

Information concerning the thickness of the Citronelle formation in Louisiana is meager. The formation has been observed through a vertical range of over 150 feet, and may safely

[1] Crider, A. F., and Johnson, L. C., Underground water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 159, p. 32, 1906.

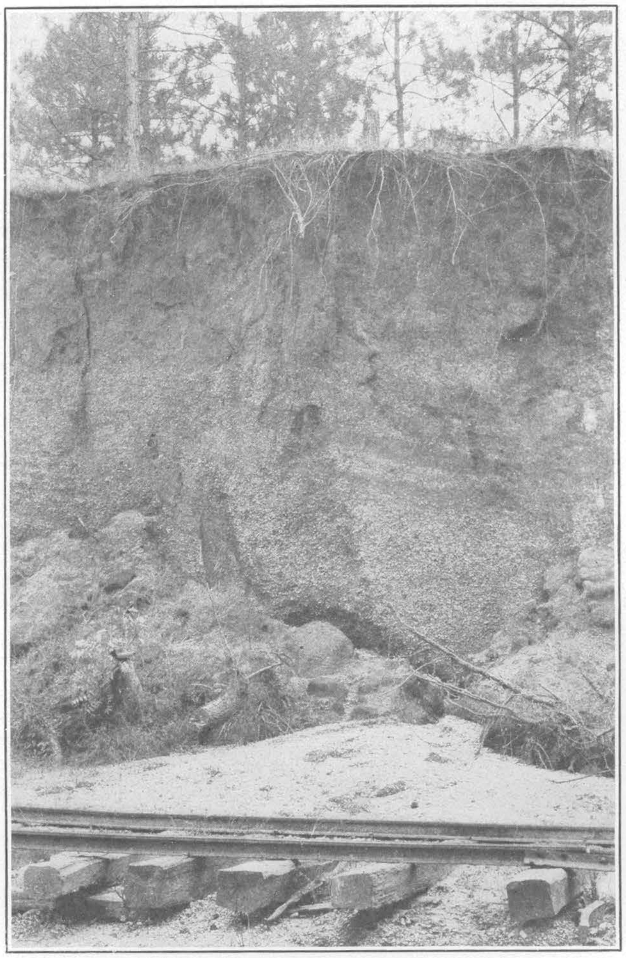


A.

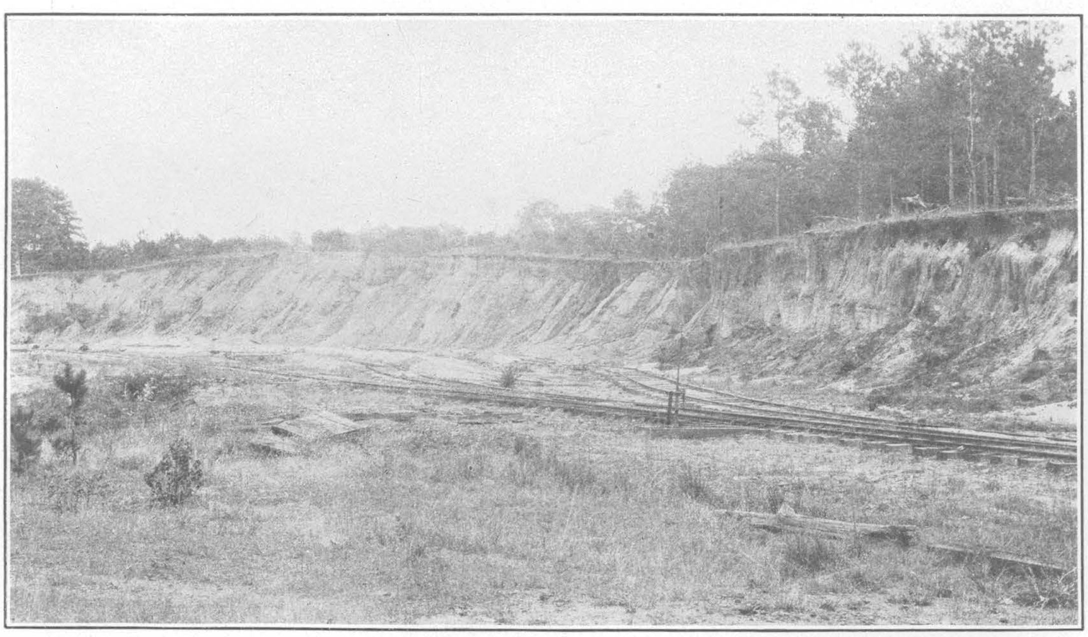


B.

SILT UNDERLAIN BY SAND AND GRAVEL OF THE CITRONELLE FORMATION, ROCKY SPRINGS, MISS.



A.



B.

GRAVEL PIT 1 MILE SOUTH OF WEATHERSBY, MISS.

Photographs by E. W. Shaw.

be credited with a minimum thickness of that amount, and this agrees with the thickness assigned to the formation in the well at Ludington. (See Pl. XLIII, in pocket.) East of Mississippi River the well at Bass penetrated 90 feet of yellow clay and 10 feet of sand, like the materials exposed at Port Hickey. This portion of the section is referred to the Pleistocene. It rests on 220 feet of clay that is regarded as the southward extension of the clays found in the upper part of the Citronelle formation in southern Mississippi, and the cherty sands and chert gravels immediately below this clay may safely be correlated with the sand and gravel that form the basal part of the Citronelle formation. This would give a thickness of 400 feet for the formation at Bass, and if the subjacent clay is included the thickness is still greater. Near the coast the deposits of Pleistocene sand, gravel, and clay can not be separated from the Citronelle formation, and its thickness has not been determined, though it probably thins rapidly in that direction.

TOPOGRAPHY.

GENERAL FEATURES.

The Citronelle formation occupies an area where the characteristic topography of the seaward margin of the Coastal Plain changes to the more diversified topography of the Tertiary beds. The contrast between the varied physiographic expression of this formation and the relatively uneroded terraces of Pleistocene age farther south is striking and would serve as a basis for mapping the seaward margin of the formation except where remnants of the Pliocene plains have been preserved. The landward margin of the formation could not be so readily distinguished by this method, because the topography of the older formations is similar to that of the Citronelle.

The original surface of the formation was a series of plains with gentle slopes toward the Gulf (see Pl. XXXII), but its present topography is the result of dissection so thorough that only a small percentage of the area remains level, the surface being mainly reduced to slopes interrupted by terraces, though near the coast a coating of materials of more recent age obscures the original surface. The general homogeneity of the deposits that constitute the formation permits the drainage channels to form under the influence of the original slope and independent of the stratigraphy. Each of the major streams has numerous tributaries, providing a dendritic drainage that is adequate for nearly all the area covered by the formation. In a few places may be seen remnants of the original surface of the formation, with drainage so deficient that they are partly submerged during periods of prolonged rainfall. On these remnants the variations in level are so slight that they are scarcely noticeable except where there are ponds either in the form of small rounded or elongated depressions overgrown with cypress and other swamp vegetation.

Some of the higher hills, especially those with flat tops, are remnants of the surface of the oldest plain, and by noting their elevations it is in places possible to reconstruct an upland having a maximum elevation of a little more than 500 feet above sea level. However, some of the hills are mere erosion remnants, the original surface having been wholly removed, though the rate of degradation has been sufficiently uniform locally to preserve a certain amount of uniformity in elevation over small areas. This condition is found where a bed of resistant material, such as gravel, is encountered, and a general seaward inclination results because such beds have a slight dip in that direction. The slope of the original surface of the formation remained nearly undisturbed after the time of deposition, because the formation was raised bodily to its present height with only slight change in attitude resulting from a gentle warping of its surface. The presence of remnants of terraces in the valleys that cross the Pliocene upland shows that the Citronelle formation has been terraced since the formation of the highest plain. The lower plains resemble the upper one in topography, but they are much narrower and the continuity of their deposits with those beneath the upper plain suggests that the materials of the lower plains were laid down in the closing stages of the Pliocene.

The range in elevation of the exposures belonging to the Citronelle formation amounts to over 450 feet, because the formation crops out in a few places near the level of the Gulf, and its outliers cap some of the high hills in the areas underlain by Oligocene formations. The average difference is about 250 feet, and if the upper surface of the formation is considered, the range is from about 170 feet on the seaward margin to more than 500 feet on some of the higher outliers farther inland. In general, the increase in altitude is comparatively rapid, the surface rising from about 170 feet to approximately 300 feet within a distance of a few miles, and upon this portion of the formation narrow seaward-facing plains are developed.

PLAINS.

SUBDIVISIONS AND GENERAL CHARACTER.

The surface of the Citronelle formation is divided into four plains, designated, in descending order, the Brookhaven plain, the Sardis plain, the Canton plain, and the Loxley plain. (See Pl. XXXII.) This arrangement is also in the order of age, the Brookhaven plain being the oldest and the others being successively younger. Each plain may be divided into two portions that merge with each other at their points of contact and may be called stream terraces and interstream plains. It has been customary to speak of these features as fluviatile and marine, though the propriety of such a designation may well be questioned, because some portions of the interstream plains are of as distinctly fluviatile origin as any portion of the stream terraces. The exact position of the contact between the deposits of the two types no doubt varied during the progress of deposition, the fluviatile sediments being pushed beyond the limits of the adjacent valley walls where the material was being carried seaward in the form of deltas and retreating into the valleys where estuaries were developed. For these reasons the terms stream and interstream, although arbitrary, are used instead of the more expressive but less accurate terms fluviatile and marine.

BROOKHAVEN PLAIN.

DISTRIBUTION.

The Brookhaven plain, named from Brookhaven, Miss., where it is well known, is the oldest and highest of the Pliocene plains and formerly occupied an area larger than the combined area of all the other Pliocene plains. Its interstream portion forms a belt from 10 to more than 60 miles in width, extending from western Florida across Alabama, Mississippi, and Louisiana into southeastern Texas. The original width of this plain can not now be determined accurately because some portions of the deposit have been removed by erosion, but it must have been more than 30 miles wide north of the Alabama-Florida boundary and 60 miles wide in western Mississippi, from which it narrowed rapidly to somewhat more than 10 miles in southeastern Texas.

The stream terraces of the Brookhaven plain are not well known outside of the Mississippi Valley, where they have been studied by E. W. Shaw.[1]

ALTITUDE.

Because of subsequent erosion and deformation the altitude of the Brookhaven plain as it now appears is variable, being from about 350 to 420 feet above sea level in western Alabama, from 420 to more than 520 feet in western Mississippi, about 320 to 380 feet in southern Louisiana, and about 340 feet in southeastern Texas.

The landward boundary of the plain is not marked by any distinct scarp but by outliers of sand and gravel, locally overlain by sandy clay. These outliers are widely distributed, but their detailed distribution has not been mapped.

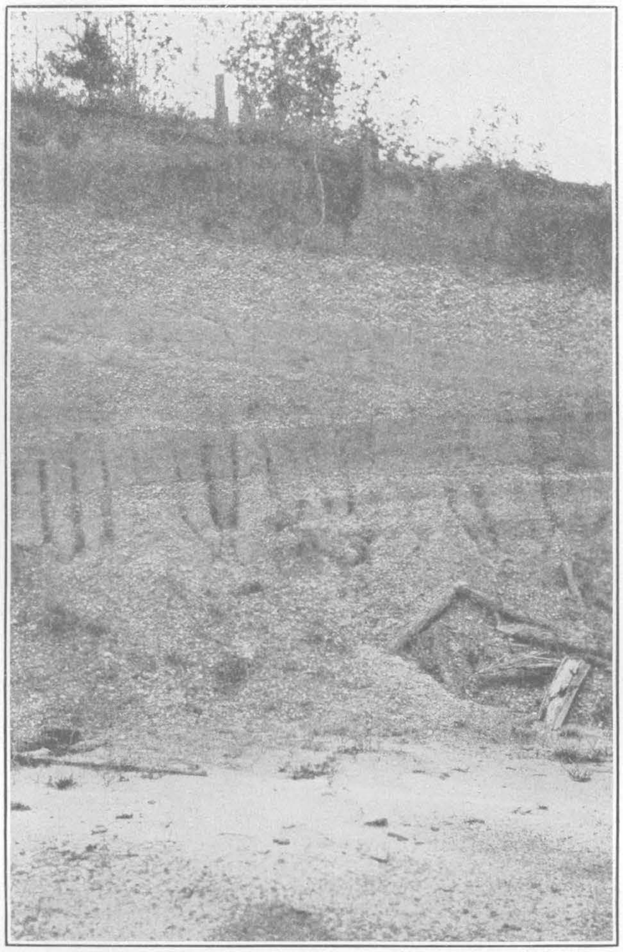
SLOPE.

The interstream portion of the Brookhaven plain slopes seaward at the rate of about 6 inches to the mile, though local variations are to be found in places where the surface has been eroded. From the highest point on this plain in western Mississippi, where its surface is as much as 520 feet above sea level, the plain slopes eastward to about 420 feet above sea level in western Alabama, or at an average of about 6 inches to the mile. The slope from western Mississippi to southeastern Texas is from 520 to 340 feet, or at an average rate of about 5 inches to the mile, in a direction south of west. As the greater portion of this descent appears to be in the eastern portion of Louisiana, the actual rate of slope near Mississippi River may have been nearly a foot to the mile, though the subsequent removal by erosion of this portion of the plain has made exact determinations impossible. The width of this plain in Alabama is variable but is much less than in Mississippi, and the slope toward the south is apparently about 2 feet to the mile.

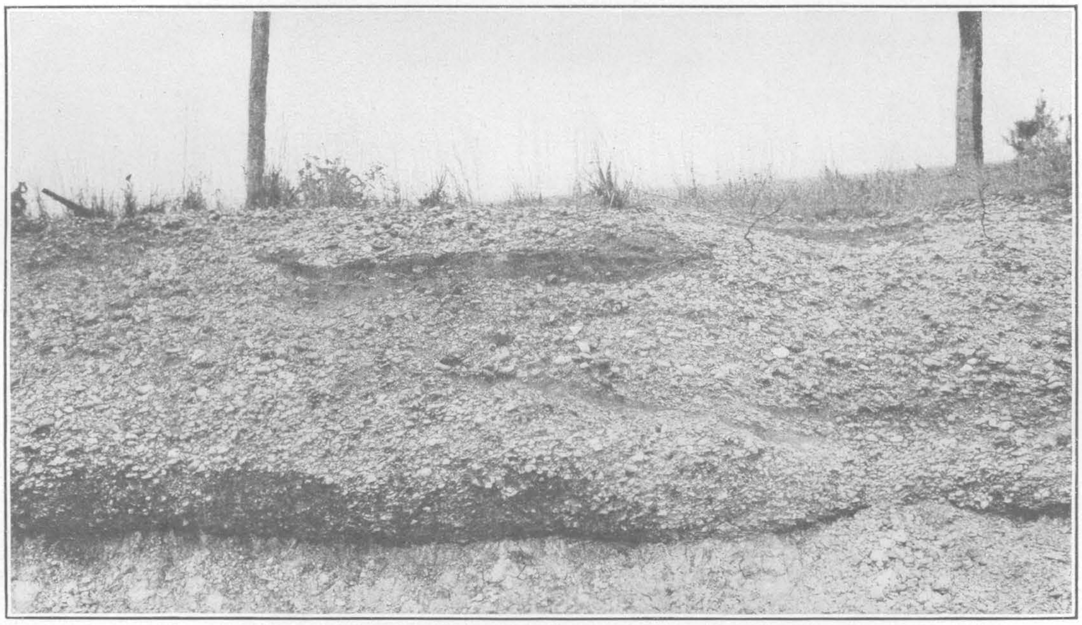
DISSECTION.

The interstream portion of the Brookhaven plain has been deeply dissected by streams, and the original surface is preserved only on the

[1] Shaw, E. W., unpublished notes.

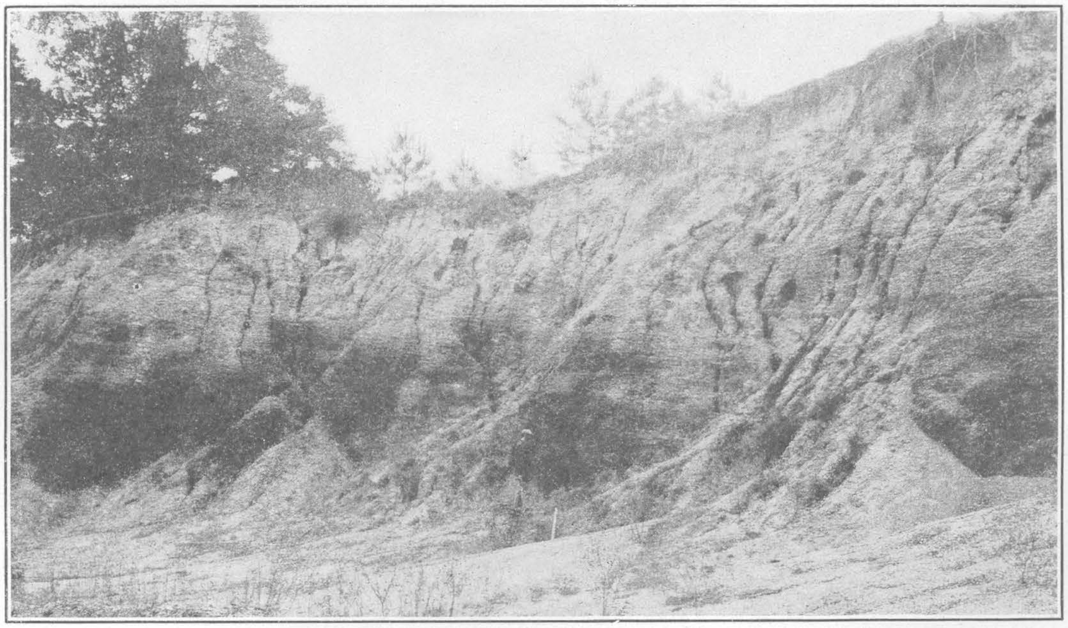


A. IRREGULAR STRATIFICATION OF SAND AND GRAVEL, GRAVEL PIT 2½ MILES SOUTH OF BROOKHAVEN, MISS.



B. COARSE FRIABLE CONGLOMERATE 1½ MILES SOUTH OF BROOKHAVEN, MISS.

A. GRAVEL 2 MILES SOUTH OF ROCKY SPRINGS, MISS.



B. GRAVEL PIT 2½ MILES SOUTH OF BROOKHAVEN, MISS.

divides and in isolated hills. These divides are generally in the form of even-topped ridges or in some localities flat areas several miles in width. A large proportion of this dissection was accomplished during the closing stages of the Pliocene, and the valleys developed at that time have not been broadened except at a few localities. This is shown by the fact that the Pliocene plains younger than the Brookhaven are represented by stream terraces in the valleys that cross the Brookhaven plain.

LITHOLOGY AND SOILS.

The material underlying the Brookhaven plain is in general coarser than that underlying the younger plains. Fine sediments, however, are the rule on the surface of the plain, and the soil derived from them is either loam or sandy loam, with subordinate amounts of clay. Where the plain has been sufficiently eroded to uncover the coarse gravels, as, for example, near Crystal Springs and Hazlehurst, Miss., stony or gravelly loams are common.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS.

The strata forming the interstream areas of the Brookhaven plain rest unconformably on the underlying formations, of upper Tertiary age, and merge with the materials beneath the next younger (Sardis) plain. The history of the formation and dissection of the Brookhaven plain forms a part of the history of the Citronelle formation, as a whole, which is discussed elsewhere.

SARDIS PLAIN.

Below the level of the Brookhaven is another plain that is well developed in the vicinity of Sardis, Miss., and is called the Sardis plain. The stream terrace of this plain in the Mississippi Valley north of the latitude of Vicksburg has been studied by E. W. Shaw.[1]

DISTRIBUTION.

Stream terraces.—A stream terrace of the Sardis plain probably originally occupied an area in the Mississippi Valley extending from eastern Adams County, Miss., nearly to central Louisiana. This is the area where it should have been widest, because here it was formed by the combined action of Mississippi River and its largest tributaries in the region. Subsequent erosion has reduced this terrace to a band less than 15 miles wide bordering the east side of Mississippi River. The width of this terrace on Pearl River, farther east in the same latitude, was from 15 to 20 miles, and the width on both Leaf and Chickasawhay rivers, still farther east, was nearly as great. On Alabama and Tombigbee rivers in Alabama this terrace was apparently twice as wide as on the rivers in eastern Mississippi. In Louisiana the stream terraces belonging to the Sardis plain have been so much dissected by erosion that it is difficult to estimate their width.

Interstream areas.—The interstream portion of the Sardis plain borders the southern margin of the Brookhaven plain and extends from central Alabama westward to southeastern Texas. In western Mississippi it has a breadth of about 30 to 35 miles; and it narrows gradually eastward to the Alabama-Florida boundary, where it is only about 15 miles wide. In western Louisiana and eastern Texas the interstream areas are still narrower, having an average width of about 10 miles.

ALTITUDE.

The altitude of the stream terraces of the Sardis plain is in general greatest near Mississippi River and declines gradually eastward to Florida and westward to Texas. They have a general slope in the direction of stream flow except in western Mississippi, where deformation has altered the original slope. On the east side of Mississippi River the stream terrace of the Sardis plain has an altitude of about 380 feet above sea level east of Vicksburg and near Woodville and Centerville. Near Natchez it is about 75 feet higher. In the Pearl River valley the plain slopes from about 410 feet a few miles north of Jackson to about 400 feet east of Brookhaven and to 360 feet near the Mississippi-Louisiana boundary. On Chickasawhay River and along the streams in Alabama and west of Mississippi River in Louisiana the slope appears to be steeper, though exact determinations of altitude have not been procured.

The altitude of the inner margin of the interstream plain in western Mississippi is about 420 feet, in western Alabama about 350 feet,

[1] Shaw, E. W., unpublished notes.

and in western Louisiana about 320 feet. The outer margin of the plain has an altitude of about 350 feet in southwestern Mississippi, 310 feet in western Alabama, and 270 feet in western Florida. In western Louisiana and eastern Texas the outer margin has an altitude of about 270 feet.

The width of the plain is variable, being from 30 to 35 miles in western Mississippi, 10 to 15 miles near the Alabama-Florida boundary, and 8 to 10 miles in eastern Texas. The narrowing of the plain both to the east and west of its place of maximum width is gradual, though marked local variations are found where the terrace has been partly removed by erosion.

SLOPE.

The slope of the stream terraces of the Sardis plain was probably originally steep, but the exact rate can be determined on very few streams because there are few reliable determinations of altitude. In western Mississippi deformation has given the stream terrace a slope away from the coast from Natchez to Vicksburg at the rate of about 6 inches to the mile. From Natchez southward it slopes seaward at the rate of about 9 inches to the mile. The slope of the interstream plains has been less affected by changes resulting from deformation and, if the steep descent from the Brookhaven plain is omitted, amounts to about 1 foot to the mile in western Mississippi, between 2 and 3 feet to the mile near the Alabama-Florida boundary, and about 3 feet to the mile in western Louisiana and eastern Texas.

DISSECTION.

The Sardis plain has undergone somewhat less erosion than the Brookhaven plain, though locally the stream terraces have been entirely removed. In general the terraces have been reduced in area by the meandering of the major streams and have been separated into small isolated plains by the erosion of tributary streams.

The interstream plains are extensively eroded near the principal streams, but on some of the divides there are still remnants of the original surface from 5 to more than 10 miles wide. Most of these remnants are crossed by shallow channels of wet-weather streams that provide adequate drainage, but in a few places, as, for example, near Atmore and Georgetown, Ala., the surface of the plain is so flat that shallow ponds form during wet weather. Even near the Mississippi Valley at Centerville and Woodville some portions of this plain are well preserved, being trenched by very shallow valleys, but the conditions here are favorable for the preservation of the original surface, because during the development of the drainage of southwestern Mississippi the stream encountered ledges of hard rock similar to that at Fort Adams at depths of 40 to 120 feet below the surface of the Sardis plain, and this hard rock retarded the erosion and resulted in the partial preservation of the original Pliocene surface where it would otherwise have been destroyed.

LITHOLOGY AND SOILS.

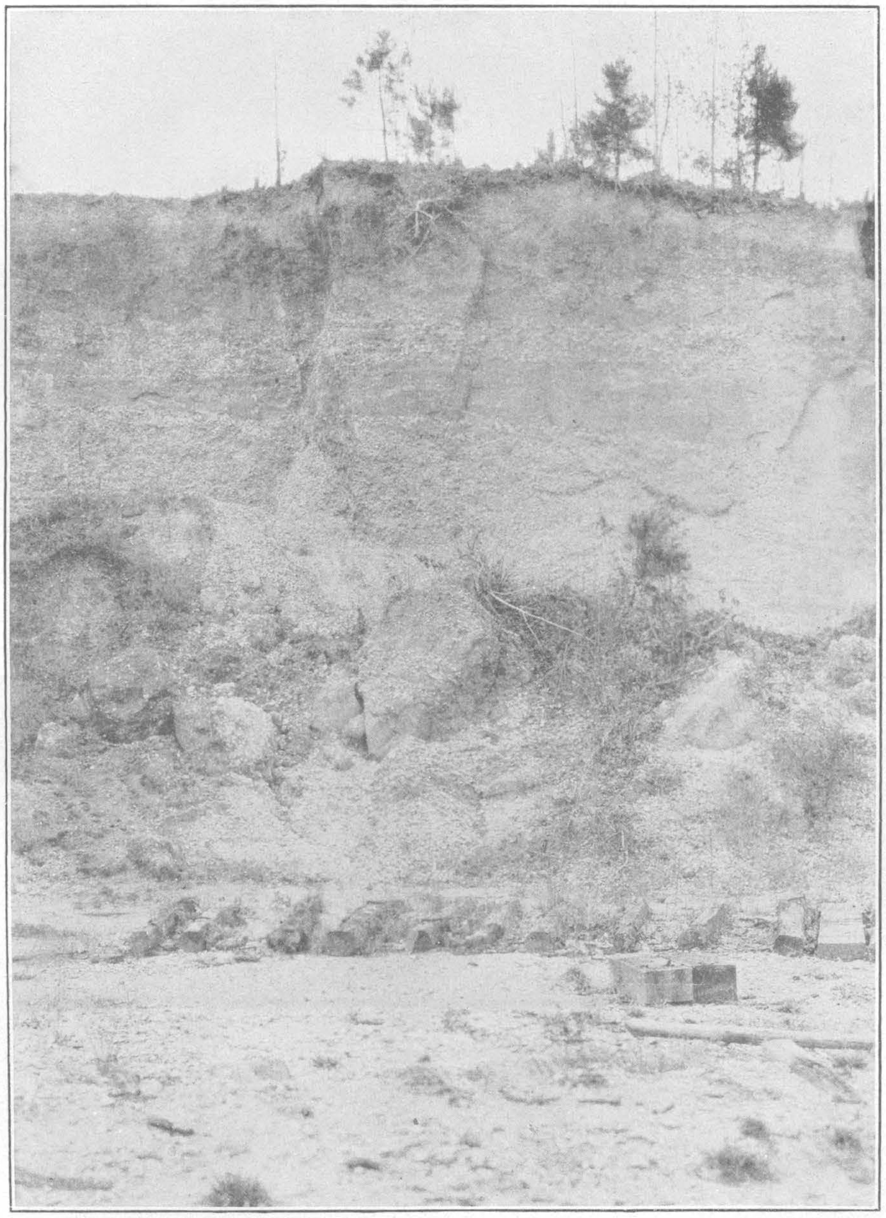
The materials beneath the Sardis plain are essentially the same as those beneath the Brookhaven plain, consisting of coarse cross-bedded sands and gravels near the base of the deposits overlain by finer sands and sandy clays. In general the gravels are finer than in the deposits of the Brookhaven plain, though near Mississippi River coarse gravels are found beneath the landward margin of the Sardis plain. Gravels are not abundant except in the area where sediments were supplied by Mississippi River. The upper member of the plain is a sandy clay of red or yellow color, and where the surface of the underlying Tertiary formations was high, as at Clinton and Woodville, Miss., this material rests directly upon them, the basal sands and gravels being absent.

The soils derived from the weathering of the surface materials of the Sardis plain are either loam or sandy loam, though in a few places where the upper member has been removed by erosion gravelly loam is found.

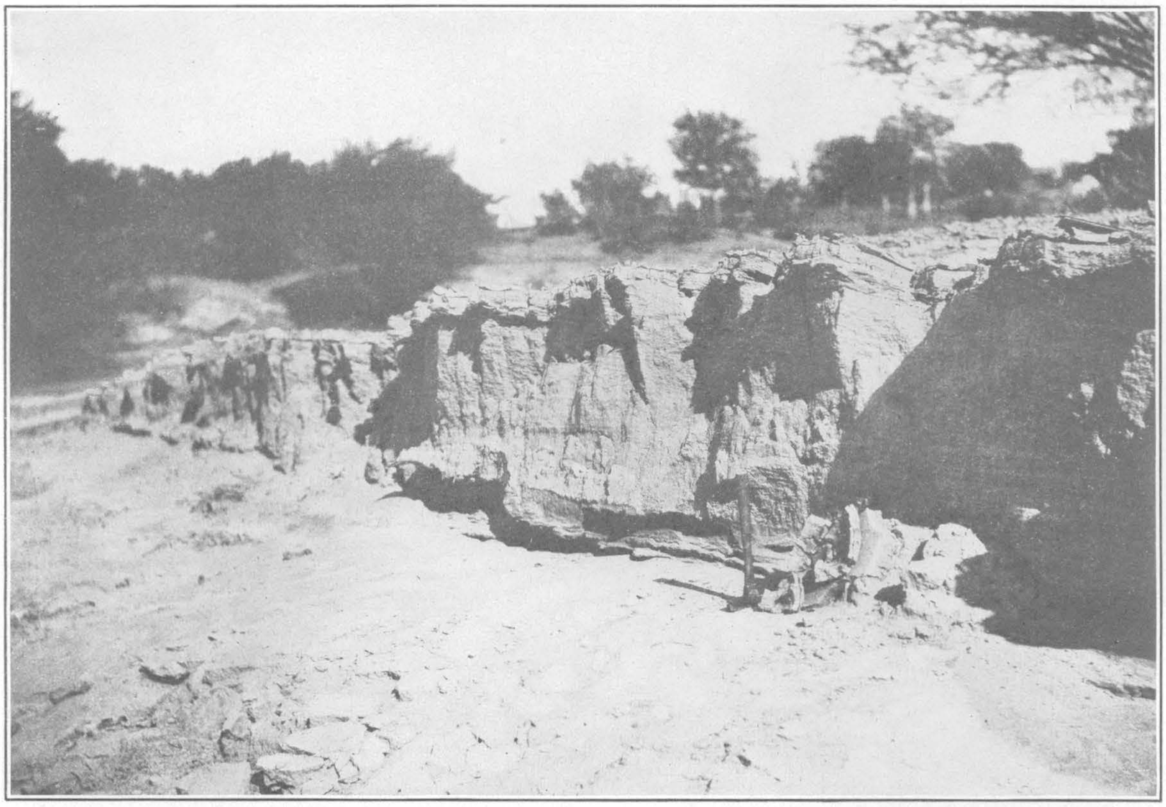
STRATIGRAPHIC RELATIONS OF THE DEPOSITS.

Near the north edge of the Sardis plain the stream-terrace deposits rest unconformably on the deposits of the Brookhaven plain. Farther north remnants of the Brookhaven plain are above the level of the base of the Sardis plain, and the deposits of the latter plain rest unconformably on older Tertiary formations.

The interstream deposits of the Sardis plain are continuous with those of the Brookhaven plain and were deposited when the sedimenta-



A CLOSE VIEW OF GRAVEL AND CONGLOMERATE AT PIT SHOWN IN PLATE XL, *B.*



A. CLAY FRAGMENTS DERIVED FROM UNDERCUTTING BY A SMALL STREAM, SULPHUR CREEK, LIVE OAK COUNTY, TEX.

B. A CLOSE VIEW OF THE FRAGMENTS SHOWN IN PLATE XLII, *A.*

Photographs by T. W. Vaughan.

tion was pushed farther seaward because of a slight general change in the altitude of the land. The change was apparently gradual, and the zone of rapid sedimentation was carried progressively seaward with continuous deposition along the margin of the older plain. This may have resulted in partial unconformity between the deposits of the two plains, though probably the unconformity was not greater than at many other places within the deposits beneath the plains.

ANTON PLAIN.

The Canton plain borders the seaward and streamward margins of the Sardis plain and originally formed a continuous belt at a slightly lower level than the Sardis plain. The name is applied by Shaw [1] to a stream terrace of this plain at Canton, Miss., and is extended to other stream terraces that can be correlated with that one and to the interstream plains that merge with the stream terraces at the seaward ends of the valley.

DISTRIBUTION.

Stream terraces.—Although the stream terraces of the Canton plain are better preserved than those of the older plains, they are represented only by mere fragments of the original deposits. The terrace in the Mississippi Valley doubtless had a width of many miles, but remnants in western Mississippi are 10 to 12 miles from the present position of the river. This terrace has probably been entirely removed by erosion in the area between Mississippi and Ouachita rivers and it has not been recognized between Ouachita and Red rivers.

The stream terraces of the Canton plain have been noted at a number of places in the valley of the rivers of eastern Mississippi and western Alabama, but the observations have not been sufficiently systematic to warrant discussing the distribution of the terraces in detail. In western Louisiana and southeastern Texas still less detailed information has been obtained concerning their distribution, though a poorly preserved terrace at an elevation of 285 feet on the east side of Sabine River between Neame and Evans Ferry is tentatively correlated with the Canton plain.

Interstream areas.—The interstream portions of the Canton plain are well developed in Louisiana east of Mississippi River and extend across southern Mississippi and Alabama into western Florida. In Louisiana the interstream areas of this plain extend westward from a point a few miles west of Woodworth, passing north of De Ridder and across the State line into eastern Texas.

The original width of the interstream areas of the Canton plain in southern Mississippi and the adjacent portions of Louisiana was about 12 to 15 miles, and they narrow eastward to Baldwin County, near the Alabama-Florida boundary line, where the width is approximately 6 to 8 miles. In western Louisiana and eastern Texas the interstream areas are about as wide as those in Alabama.

ALTITUDE.

The stream terraces of the Canton plain are lower than those belonging to the older plains, though considerable local variation is found, the altitude depending on the size of the stream. As a rule, the stream terraces of all the plains naturally rise to higher levels and away from the coast have steeper gradients on the small streams than on the large. An exception is found in the Mississippi Valley, where the terrace in the vicinity of Newmans Grove, east of Vicksburg, rises to only about 300 feet above sea level and the altitude increases slightly toward the coast, being nearly 380 feet east of Natchez. Thence the terrace slopes southward to about 350 feet near the southern boundary of Mississippi. Both inner and outer margins of the stream terraces were originally marked by scarps, but in many places these features have been destroyed by erosion.

The interstream areas in southern Mississippi range in altitude from about 350 feet on the landward margin to about 280 feet on the seaward margin. The altitude decreases gradually from western Mississippi to western Alabama, where the landward margin is about 310 feet above sea level and the seaward margin 250 feet, and there is a still further decrease in western Florida, where the altitude of the landward margin is about 270 feet and that of the seaward margin about 220 feet. A similar but slightly more rapid descent west of Mississippi River brings the surface of the plain to about the same altitude in western Louisiana and eastern Texas that it has near the western boundary of Florida.

[1] Shaw, E. W., unpublished notes.

The margins of the interstream plain are not bounded by distinct scarps but they are marked by an increase in gradient. At many places the margins have been destroyed by erosion, because the changes in gradient have furnished favorable places for the development of lines of drainage.

SLOPE.

The slope of the stream terraces of the Canton plain is in general seaward, though the rate is not easily determinable because of the lack of detailed information. The terrace on the east side of Mississippi River from Newmans Grove to the latitude of Natchez forms an exception because of deformation subsequent to deposition. The slope of this terrace is reversed, being northeastward, and it amounts in the aggregate to 30 feet in 60 miles, or about 6 inches to the mile. From the latitude of Natchez to the northern boundary of Louisiana the slope of this terrace is southward at the rate of about 9 inches to the mile.

The interstream portions of the Canton plain slope more steeply than those of the Sardis and Brookhaven plains, the average slope being from 2 to 3 feet to the mile, if the steepened landward margin is disregarded. Local variations are common, however, and in many places the original slope has been destroyed by erosion.

DISSECTION.

Both stream and interstream portions of the Canton plain have been greatly dissected, and the remnants now appear as isolated areas having nearly level surfaces or as even-topped divides between the major streams. In places these divides are several miles in width, but the undrained areas are smaller than those on the Sardis plain. This is attributed to the fact that the Canton plain was narrow and the original surface had a steeper slope than the Sardis plain.

LITHOLOGY AND SOILS.

The lithology of the Canton plain is, in general, like that of the Citronelle formation as a whole. Gravel is less abundant in the deposits beneath this plain than in those beneath the Sardis and Brookhaven plains, though it is reported in some wells and is exposed in a few deep valleys. The surface of the plain is composed of fine sandy clay and silt similar to the material forming the surface of the older plains and the soils are chiefly loam and sandy loams.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS.

The materials underlying the Canton plain doubtless have the same stratigraphic relations as those beneath the Sardis plain, but the exposures are not deep enough to permit satisfactory observations.

LOXLEY PLAIN.

The lowest of the Pliocene plains that are underlain by deposits of the Citronelle formation is well preserved in the vicinity of Loxley, Baldwin County, Ala., and is therefore named the Loxley plain.

DISTRIBUTION.

Stream terraces.—The Loxley plain has a width of only a few miles where it is represented by remnants of stream terraces. In the Mississippi Valley the original extent of the stream terrace belonging to this plain can not be easily determined, though in the vicinity of Sicily Island, where the terrace is the result of erosion and deposition by Mississippi and Ouachita rivers, it may have been 30 to 40 miles wide. The average width in the Mississippi Valley between Sicily Island and Vicksburg was probably not much greater than 25 miles. The original width was apparently less than 10 miles in the valleys of the rivers in eastern Mississippi and western Alabama and Florida, except in the Alabama and Tombigbee drainage basins, where this terrace is more than 25 miles wide at its southern margin.

Interstream areas.—The interstream areas of the Loxley plain occupy a belt between the Canton plain and the oldest Pleistocene terrace. They vary much less in width than the older terraces of the Citronelle formation, being as wide in western Florida and Alabama as in southern Mississippi and eastern Louisiana. The average width of these areas is about 8 miles and the maximum is about 15 miles. On the eroded outer margin of the plain the underlying deposits have been exposed in places by the removal of the younger beds, and if the maximum width should be extended to include these exposures it would amount to slightly more than 30 miles. However, these more or less isolated exposures represent surfaces eroded during the Pleistocene epoch. The width of the interstream portions of the Loxley plain in southwestern Louisiana and southeastern Texas is about 8 miles. This plain is well developed in an area that extends from Forest Hill to De Ridder, La., and thence westward, passing a few miles south of Newton, Tex.

ALTITUDE.

The stream terraces of the Loxley plain vary in altitude, being higher on the small streams than on the large, and they increase in altitude away from the coast. This generalization, however, does not apply to the terraces of the rivers in western Mississippi, where the altitude has been changed by deformation. East of Vicksburg the terrace in the Mississippi Valley is about 280 feet above sea level, and east of Natchez the altitude is nearly 40 feet higher. From Natchez southward to the Louisiana boundary it declines to about 270 feet above sea level. The terrace on Pearl River has an altitude ranging from about 230 feet northwest of McNeil to about 300 feet near Monticello and 320 feet near Jackson. The altitudes observed on Leaf River range from about 250 feet near Hattiesburg to about 200 feet near Merrill, and those in western Alabama, on the west side of the Tombigbee, from about 250 feet east of Seaboard to about 200 feet northwest of Mobile. On Conecuh River they range from 200 feet near the Alabama-Florida boundary to about 230 feet east of Kirkland. Terraces of this age were recognized as far east as Yellow River, in northern Florida, where the altitudes obtained by barometric readings were somewhat greater than 200 feet, and near Crestview, where the altitude on the interstream plain is about 190 feet.

On the west side of Mississippi River, in Louisiana, the gravel deposits on the top of the Sicily Island hill and on the upland west of Ouachita River are tentatively referred to a stream terrace of the Loxley plain, and other stream terraces at altitudes of 200 to 225 feet were noted farther west, on the west side of Red River near Woodworth and on Sabine River west of Neame.

In Louisiana east of Mississippi River the interstream areas stand at 280 to 220 feet above sea level, and the altitude decreases slightly from the Mississippi Valley eastward, being 250 to 210 feet in southern Mississippi, 250 to 190 feet in western Alabama, 230 to 170 feet near Loxley, in southern Baldwin County, Ala., and 220 to 160 feet near Yellow River, in western Florida. All these figures should be regarded as approximate, because neither landward nor seaward margins of the interstream portions of the Loxley plain are very sharply defined.

West of Mississippi River the decrease in altitude is more rapid than east of it, bringing the inner margin of the plain down to about 220 feet above sea level in central Louisiana. Farther west, near Forest Hill, in central Louisiana, the altitude ranges from 220 to 180 feet. From central Louisiana to southeastern Texas the altitude is nearly uniform and about the same as near Forest Hill. Along the Kansas City Southern Railway, which crosses this plain, the landward margin just north of De Ridder has an altitude of about 220 feet and the seaward margin north of Bon Ami is approximately 40 feet lower. South of Newton this plain is represented by the tops of the hills that rise 180 to 220 feet above sea level.

SLOPE.

The stream terraces of the Loxley plain have a general slope in the direction of stream flow except in a part of the Mississippi Valley, where deformation since the materials were laid down has caused a reversal of the normal direction. Between southern Warren County and southern Jefferson County, Miss., the Loxley stream terrace slopes northeastward at about the same rate as the stream terrace of the Canton plain. Accurate determinations of slope are not possible, because measurements of altitude are difficult to procure on account of the thick mantle of loess that covers the Pliocene plains. From southern Jefferson County, Miss., to northern Louisiana the terrace slopes southward at the rate of 1 to 1½ feet to the mile.

On Pearl River the stream terrace of the Loxley plain has very little slope between Jackson and Monticello, but south of Monticello it slopes toward the coast at the rate of about 1 foot to the mile. The terrace on Leaf River slopes a little more than 1 foot to the mile from Hattiesburg to Merrill, and the terrace on the west side of Tombigbee River slopes about 1 foot to the mile. On Conecuh and Yellow rivers the slopes may be somewhat higher than farther west, amounting to 1½ feet to the mile, though the altitudes used in making this estimate were determined with a barometer and are subject to correction. In western Louisiana and eastern Texas there are few data for estimating the rate of slope of the stream terraces, but such observations as have been made indicate slopes of at least 1 foot to the mile.

The slopes of the interstream areas of the Loxley plain amount to 5 or 6 feet to the mile, but these figures include a comparatively steep descent along the landward margin of the plain from the surface of the Canton plain, and in addition some allowance should be made for the erosion of the seaward margin in post-Pliocene time. Observations on uneroded surfaces indicate a slope of 1 or 2 feet to the mile, the rate of slope being apparently greatest near Mississippi River and decreasing slightly both to the east and to the west.

DISSECTION.

The Loxley plain is much less eroded than the Sardis and Brookhaven plains, but it shows somewhat greater erosion than the next older or Canton plain, because it forms a fringe about this plain and was attacked first by the streams in post-Pliocene time. In addition, the seaward margin of the Loxley plain was eroded at the time of the formation of the oldest Pleistocene terrace. In general, the surface of the Loxley plain has been reduced to slopes except on the divides between the large streams, where there are flat areas several miles wide covered by small undrained depression.

LITHOLOGY AND SOILS.

The lithologic description of the Citronelle formation as a whole will apply in a general way to the materials beneath the Loxley plain, though the exposed materials, except where there has been an unusual amount of erosion, are largely sandy clays or silts. Locally fine or moderately coarse gravel has been exposed by erosion, and well records show that gravel exists at many places where it is not exposed. In general, the percentage of fine material in the deposits beneath the Loxley plain is greater than in those beneath the older plains of the Citronelle formation. The soils are largely loams and sandy loams.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS.

The stratigraphic relations of the materials underlying the Loxley plain are similar to those of the deposits underlying the older plains. There is apparently no marked break between the sediments beneath the Loxley plain and those beneath the Canton plain, except possibly in the upper portion of the deposit, where a slight subsidence during the closing stages of deposition on the Loxley plain may have permitted the transgression of the sediments upon the margin of the Canton plain. The exposures are so poor that opportunities to examine the contacts between the deposits of these plains are rare. In the stream valleys the terrace sediments of the Loxley plain were deposited unconformably on those that were laid down during earlier Pliocene time, and farther up the streams they are conformable on still older formations.

PALEONTOLOGIC CHARACTER.

The scarcity of organic remains in the Citronelle formation has long been a bar to its satisfactory discrimination and correlation. Heretofore no identifiable fossils have been discovered except fragments of silicified wood, which might have been derived from some older formation by erosion. The numerous exposures that were studied during this investigation furnished no remains of either fresh or salt water organisms, though possibly this might be explained in part by the weathered character of the outcrops. It is probable that the processes of weathering would remove traces of shells from sands, but even where unweathered layers of sand or clay have been examined they have, except in two places, been found to be nonfossiliferous. Failure to find remains of marine organisms warrants the assumption that the beds are largely nonmarine, and this view is strengthened by the character and arrangement of the sediments. The absence of fresh-water fossils is probably due to the scarcity of animal remains capable of preservation, together with the unfavorable conditions for preservation resulting from the mode of origin and character of the deposits.

The only identifiable organic remains obtained from the Citronelle formation were fossil plants collected in a cut on the Mobile & Ohio Railroad south of Lamberts and at Red Bluff, on the shore of Perdido Bay, in Alabama. At both places the fossil plants occur in beds of dense clay, stained black by organic matter, and they owe their preservation to the character of the matrix, which excluded the air, thus preventing their destruction by weathering. These fossils are described by Mr. Berry on pages 195–208, and further reference to them is unnecessary. The relation of the leaf-bearing clays to the other beds in the exposures where they were collected is similar to the relations shown by many of the other lenses of clay that occur in the formation.

The leaf-bearing clays are near the top of the formation, and those at Red Bluff are somewhat younger than those at Lamberts. The plants collected at Lamberts were obtained from a bed that is younger than the outliers that cap the high hills to the north, but the upper portion of the formation near the coast is younger still. The fossils at Red Bluff were found in the upper beds near the coast, though no doubt some higher layers have been removed by erosion at this locality. The leaf-bearing clays are younger than most of the coarse gravels that form outliers along the landward margin of the formation, because the gravels pass under the clay beds on the uplands and are found in wells near the coast. Beds deposited contemporaneously with those near the coast extend into the valleys, where they form terraces in the valleys of the principal streams. These terraces contain coarse gravels a short distance away from the coast and present conditions unfavorable for the presence of fossils. The beds penetrated by wells at Fort Morgan and Pensacola are apparently marine, and marine Pliocene fossils may have been found in wells elsewhere along the coast, though samples of drillings are seldom preserved and information concerning such fossils is fragmentary.

ORIGIN.

The Citronelle formation contains practically every variety of clastic sediments, and nearly all of them may be represented in a section only a few feet thick, many small exposures ranging through all the intermediate stages from coarse gravel to fine clay. In mineral composition the deposits are similar to ordinary clastic sediments, being made up largely of quartz or silicates, such as kaolin. The many variations in physical character, together with rapid alternations of materials of different sizes (see Pls. XXXVI–XXXIX), indicate changing conditions of sedimentation such as are characteristic of areas where there are many variations in direction and velocity of the currents transporting the materials. These conditions prevail in the valleys of streams subject to changes in velocity produced by floods and quiet water. Similar conditions are found along shore lines where rivers supply detritus of varying coarseness to be reworked by waves. More detailed observations on sedimentation might reveal characteristic differences between fluviatile deposits and those made along the margin of the sea, with intergradations where deposits of the two kinds merge, but in the absence of such observations it is not always easy to distinguish the deposits of the two classes.

The character and arrangement of the sediments comprising the Citronelle formation suggest that they are in part fluviatile, in part estuarine, and in part shallow-water deposits made at or near the strand line, where there was some wave action. The coarse gravels are much less rounded than similar materials that have been subjected to prolonged subaqueous erosion and are therefore thought to be of fluviatile origin. This belief is supported by the confused character of the stratification, which shows lenticular bedding and an alternation of imperfectly assorted sediments of different grades. It is possible, however, that some of the gravels were deposited along the shore, where they were partly reworked and redeposited by waves.

The absence of remains of marine organisms and the character and arrangement of the Citronelle sediments suggest that they are mainly fluviatile. Attempts to explain the lack of marine fossils by supposing that they have been removed by solution during the processes of weathering are not entirely satisfactory, because comparatively fresh exposures of the formation have been examined at many localities without finding traces of marine organisms.

On pages 194–195 Mr. Berry discusses the ecologic conditions of the plants whose fossil remains have been found. He suggests barrier beaches, possibly with sand dunes, a mile or more wide, crossed by inlets and inclosing shallow lagoons. These lagoons, he thinks, must have been a mile or more in width, and still wider where large rivers formed estuaries. Dunes were probably built along the landward margins of the lagoons. This description agrees with the general features of portions of the Gulf coast to-day and may represent conditions that existed at the places where the plants grew. It does not, however, seem possible to account in this way for the various kinds of deposits found in the formation throughout a large portion of the area where it is exposed.

The conditions described by Mr. Berry might account for all the sediments except the fluviatile deposits, though it is more probable that at the mouths of some of the large streams like the Mississippi the sediments were built into broad deltas. Under the influence of shore currents some of the materials brought to the shore by the streams were spread across the interstream spaces until they coalesced to form extensive deposits. This condition harmonizes with the theory of the formation of lagoons, beaches, and dunes alongshore. As the sea encroached upon the land the beaches and dunes would be destroyed and the lagoons filled by the action of the waves, and thus distinctive shore features would not be recognizable in the formation. Probably at some stages of deposition rapid subsidence would produce estuaries where at times of relative quiescence deltas had been formed. Sometimes estuaries and deltas might both exist along the same shore, just as the broad Delta of the Mississippi is flanked on one side by the estuaries of southwestern Louisiana and on the other side by the estuaries of southeastern Mississippi and southern Alabama.

Certain features indicate that the conditions were not uniform and that there may have been many changes in the site of most rapid sedimentation. For example, at Brookhaven there is a thick deposit of sand at the base of the formation, overlain by coarse gravel, and this in turn by sands and clays. This alteration would result from a shifting of the direction of the principal currents that transported the sediments, or from reversal of movement along the strand line during the progress of deposition, or from uplift farther inland, causing enough increase in velocity to permit the streams to spread gravel over the basal sands. While material was being laid down upon the upland the site of rapid sedimentation was shifted landward and the beds previously deposited were covered by finer sediments. At the same time the older shore features were destroyed, and in this way fine sediments were deposited some distance landward upon the coarse fluviatile sediments. However, that the fine materials did not extend entirely across the area in which the Citronelle formation is now exposed is indicated by the fact that the erosion of the formation has not been sufficient to remove a great amount of material and the landward edge of the formation is now composed of coarse sands and gravel. If fine sands and clays had been deposited on this portion of the area erosion would probably have been insufficient to remove them entirely.

The emergence of the seaward margin of the formation permitted the duplication of some of the shore phenomena of the earlier depression, including the formation of deltas, bars, and other shore features, but these features have been destroyed by subsequent erosion. Intermittent changes in level during emergence account for the terracing seen at high levels in the present valleys, and it is probable that the fossil plants now found in the upper portion of the formation belong to this period.

The upper sand beds show a renewal of the quiet-water conditions that existed before the deposition of the gravel, and in the closing stages of Citronelle time the deposits were fine sand and silt, such as are laid down by flood waters of a muddy stream at times of overflow. This overflow began when the streams eroded their channels below the general level of the deposits already made and continued as long as the waters spread over the flood plains adjacent to the streams.

Some of the terraces in the stream valleys that trench the older formations represent episodes in the post-Pliocene history of the region, but those that stand at high levels were formed during the closing stages of the deposition of the Citronelle formation. Knowledge of the details of the distribution and relations of these terraces is still incomplete, but enough is known to warrant the conclusion that they merge into the deposits classed with the Citronelle formation.

The interstream portions of the Sardis, Canton, and Loxley plains were each built against the steep front of the next older plain as the result of changes in level that shifted sedimentation seaward. The changes may have been caused by general uplifting of the land, by withdrawal of the sea, or by an upward movement some distance inland that enabled the streams to carry their loads of detritus farther seaward. Of these possible explanations the last seems the least probable, because such a change would have resulted in the deposition of a larger percentage of coarse sediment along the seaward margin of the formation; moreover, the base-level of the streams was lowered, as is shown by the formation of stream terraces that coalesce with the interstream plains. This lowering of the base-level might have been the result either of upward movement of the land or of recession of the water, or of both causes operating simultaneously. The warping of the plains suggests a land movement but it does not prove that such a movement was the sole cause or even the most effective cause of the changes in base-level, though the warping was largely contemporaneous with those changes, as is suggested by the fact that the post-Pliocene terraces are not deformed.

The lowering of the base-level resulted in the removal of a portion of the deposits already formed and their redeposition along the seaward margin of the older beds. The intermittent character of the changes permitted the formation of terraces in the stream valleys, and at the same time the deposits made along the seaward margins of the older beds were built into interstream plains either by the coalescing of deltas or more probably as the combined work of streams and waves.

The closing stage of the formation of each plain seems to have been a partial submergence, which permitted the development of small lagoons and other depressions on the surface, though there is no evidence of marine erosion and deposition in the form of beach ridges such as would have resulted from vigorous wave action. Each successive stage of deposition was closed by a renewed lowering of base-level, and as the change progressed finer sediment was spread over the coarse detritus in the stream valleys. Some of the fine silt that covers the uneroded portions of the interstream plains may have been deposited as the result of a rise in the level of the streams as deltas were built seaward, though these deposits are too widely distributed to be explained as a whole in that way. Moreover, evidence of slight submergence is afforded by partly filled valleys emerging at the levels of the surfaces of some of the younger plains. That this resubmergence came at the end of the period of deposition of the materials forming the plains and not after the shaping of the existing valleys is proved by the absence of deep filling in these valleys.

SURFACE DEPOSITS.

Erosion of the surface of the Citronelle formation began at the end of Pliocene deposition and has continued down to the present time. It was accomplished by the same forces that are now active, including stream corrasion, surface wash, wind action, and the work of organisms; and although the action of these agencies may have varied in intensity at different times, evidence of such variation is not apparent. There was a constant shifting in the sites of most active erosion, and portions of the eroded materials were redeposited many times. Much of this redeposited material may be seen on the slopes, and where it resembles the subjacent deposits of Pliocene age it is not readily recognized, though in many places it may be distinguished because of the concentration of relatively coarse detritus, such as pebbles or fragments of iron-cemented sandstone or limonite, which has resulted from the partial removal of the finer materials. The redeposited materials do not form a continuous mantle but are distributed on all the slopes and are exposed in many shallow gullies, especially along wagon roads. They range in age from the earliest period of erosion of the Pliocene deposits to the present day, but in many places they have been undisturbed for a long time because of protection by vegetation.

Since the beginning of the terracing, in Pleistocene time, erosion and redeposition have been very largely concentrated on the lower slopes and in the bottoms of the valleys, and this has resulted in the formation of deposits of definite types that will be mentioned in discussing the Pleistocene deposits.

PLEISTOCENE TERRACES.

During the Pleistocene epoch extensive terraces bordered by seaward-facing scarps were formed along the seaward front of the Pliocene deposits. These terraces extend into the river valleys, where they merge with terraces of fluviatile origin. In most places the Pleistocene deposits forming these terraces are relatively thin, though near Mississippi River and other large streams thick constructional deposits were made. Names have been applied to the terraces and are used on the accompanying diagrams and in some of the sections (Pl. XXXII, p. 170), as well as in the text.

The Pleistocene age of the oldest terrace, the St. Elmo, is inferred from the fact that it merges, in the Mississippi Valley, into the Natchez formation, which is regarded as sub-Aftonian.[1] The Natchez formation contains crystalline pebbles and underlies a terrace that was doubtless formed during the Pleistocene epoch. The younger terraces, named in the order of the age, are the Port Hickey, the Hammond, and the Pensacola. The name Port Hickey is taken from a locality on Mississippi River where the typical materials of the Port Hudson formation are exposed. The Hammond terrace is named from Hammond, La., and the Pensacola terrace from Pensacola, Fla.

The level, uneroded surfaces of these terraces are in sharp contrast with the erosional features of the Citronelle formation, but they have their counterparts in the uneroded portions of the interstream plains of the Citronelle. Shallow depressions extend from the larger river valleys diagonally toward the coast, and most of them are bordered by low natural levees. These channels resemble those now being formed across the Mississippi Delta, and they show the constructional origin of the subsurface deposits. In some of the areas between the streams, seaward-facing scarps border the inner margins of the Pleistocene plains, and in places there are low ridges and shallow ponds whose long axes lie parallel to the shore line. These features show that wave action has been an influential agent in forming the surface, and it is probable that both wave and stream action prevailed at the same time along different portions of the coast and that their relative efficiency varied with the changing relations of the land and the water.

The exact relations of the different terraces to the glacial deposits is not fully known, though the St. Elmo terrace, which appears to be older than the great deposits of loess that fringe the east side of the Mississippi Valley and to be contemporaneous with the crystalline gravel at Natchez, is regarded as sub-Aftonian. The Port Hickey terrace appears to be younger than the principal deposits of loess. If this loess is considered to be of Iowan age these relations would indicate that the St. Elmo terrace is pre-Iowan and the Port Hickey terrace post-Iowan. The loesslike silt that forms the surface of the Port Hickey terrace may be of Wisconsin age, and if so, this would place the terrace in the interval between the deposition of the Iowan loess and that of the Wisconsin silt. The lower terraces must necessarily be younger than the Wisconsin silt.

In addition to the terraces of Pleistocene age a similar terrace of Recent age now rises a few feet above sea level and extends outward beneath the shallow waters of the Gulf.

WELL LOGS.

The accompanying diagrams of well logs (Pl. XLIII, in pocket) show the characteristics of the Citronelle formation at a number of localities and the relation of this and other formations penetrated in drilling the wells. The correlations with formations exposed at the surface are based on such information as could be obtained concerning the lithologic character of the materials penetrated in the wells, supplemented by the evidence of fossils. In general it may be said that the correlations represent the most probable subdivisions, though the lines between different formations are somewhat indefinite.

Well No. 1, drilled by the Baldwin County Oil Development Co. in southeastern Alabama, shows at the surface a thin deposit of sand and clay that is classed as Pleistocene because it underlies a terrace of that age. Beneath this is a thick bed of sand containing some gravel and thin beds of rock and clay, correlated with the Citronelle formation. The more clayey beds immediately underlying the Citronelle formation are classed with the Pascagoula clay, and the accuracy of this correlation is strengthened by the fact that at depths of 730 feet and more in a well drilled near this locality fossils that were classed as Miocene [1] were obtained. The materials penetrated below 900 feet in well No. 1 have been doubtfully correlated with several formations, but Claiborne fossils were identified from a collection obtained at the well.

The Fort Morgan well (No. 2) was drilled on a narrow sandy island opposite the entrance to Mobile Bay. This well is unique in showing an

[1] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 3, p. 387, 1906.

[1] Smith, E. A., The underground water resources of Alabama, p. 316, Alabama Geol. Survey, 1907.

unusually large percentage of sand. Fossils were obtained at various depths, and a list is given on page 194. According to Mr. Dall's interpretations, the Quaternary material extends to a depth of about 1,290 feet. The materials below that depth were doubtfully correlated with the Pliocene because they contain fossils that were supposed to be of Pliocene age. They may represent the seaward extension of the Citronelle formation.

Through the courtesy of Mr. A. G. Curtis, manager of the Southwestern Gas Co. at Shreveport, La., a log was obtained of the Jarvis & Meacham well No. 1, on the level upland of Mobile County at Semmes, Ala., about 12 miles west of Mobile. This well (No. 3) shows a thickness of more than 200 feet of sand and clay with a bed of gravel near the base. The gravel consisted very largely of coarse chert pebbles but included some finer pebbles of quartz. Some of the chert pebbles were more than an inch in diameter, and most of them were subangular or only slightly rounded, resembling the pebbles found farther north in Alabama and in south-central Mississippi. Beneath the sand and gravel were layers of pink and white sand and clay extending to a depth of 390 feet. All this material is included in the Citronelle formation in the diagram. From the underlying clays and associated sand beds fossils were obtained at several horizons. They were submitted to C. W. Cooke, who reported that the characteristic fossils of the Pascagoula clay were present. The well penetrated some distance into the Oligocene formations, but no fossils of that age were collected and the descriptions of the material are not sufficiently definite to permit correlations.

In southern Mississippi, especially near the coast, there is a somewhat uniform general sequence of beds, although many minor variations are recorded in the logs of wells, probably because the formations are lenticular.

The well at Bond, Harrison County (No. 4), encountered red sandy clay and white sand having a total thickness of about 190 feet. The upper portion of this material may safely be correlated with the Citronelle formation, and perhaps all of it should be so included. A thick clay bed that begins at 190 feet and the sand below it are classed as the Pascagoula clay, which is in turn underlain by a thicker bed of clay, the Hattiesburg clay. At 780 feet some chert gravel was encountered similar to that obtained in the wells at Hattiesburg at the base of the Hattiesburg clay. This gravel, associated with sand and clay, was reported at intervals to a depth of 1,120 feet, and this portion of the well section is correlated with the Catahoula sandstone.

Farther south, at Wortham, the well of the Gulf & Ship Island Railroad (No. 5) shows some 20 feet of yellow clay that is assigned to the Pleistocene. The underlying sandstones, sands, and clays, with a bed of gravel at the base, are placed in the Citronelle formation. Beneath this formation is a bed of massive blue clay, the Pascagoula clay, which is in turn underlain by gray sand of uncertain age.

The De La Morton well at Laine, Miss. (No. 6), encountered sand and clay containing tree trunks to a depth of nearly 160 feet. Beneath this material clay predominated to about 565 feet, where a bed of gravel nearly 40 feet thick was reached. This clay and the underlying gravel are classed with the Citronelle formation. Characteristic fossils of the Pascagoula clay were found at a slightly greater depth and were reported at intervals nearly to the bottom of the well. The first casing was set at a depth of 881 feet, and apparently some of the Pascagoula fossils came from a slightly greater depth and continued to appear in the cuttings long after the drill had penetrated to other formations. Tentative correlations of the deeper formations are presented on the diagram.

At Brookhaven the well belonging to the Southern Gravel & Development Co. (No. 7) encountered gravel and red sands that are classed with the Citronelle formation. The material below these beds is all designated clay, and subdivision into formations is impossible.

At McComb (well No. 8) the Citronelle formation has an apparent thickness of about 220 feet, though some doubt exists as to the correctness of the correlation of the materials designated "hard gumbo and dry gravel." This gravel did not come from the beds encountered near the surface, because a casing had been set in the well at a depth of 117 feet. Beneath the Citronelle formation the Pascagoula clay is recognized, and it is possible that the underlying Hattiesburg clay was reached.

At Osyka (well No. 9) the Citronelle formation is about 150 feet thick and is underlain by blue clay and some sand and gravel that are correlated with the Pascagoula clay. The point of contact between the Pascagoula and Hattiesburg clays is not clearly defined, and it is not possible to separate the Hattiesburg clay from the Catahoula formation.

The well at Woodville (No. 10) shows an unusual condition in southern Mississippi, where, because of the presence of relatively hard sandstone, a hill of hard Miocene sandstone (Pascagoula clay) rose high enough to be above the level of the coarse sediments of the Citronelle formation. As a consequence of this condition the material deposited on the hill represents only a portion of the upper fine-grained sediments of the formation. The diagram of this well with its thin deposits of sand and clay should be contrasted with the diagram of the Bass well, where the Citronelle formation is much thicker. These two diagrams illustrate the marked irregularity of the upper surface and the steep slope of the Miocene surface toward the coast, though it should be noted that the gradient of this surface was probably increased by downward flexing near the Pliocene shore.

At Bass, La., the well belonging to B. A. Bass (No. 11) passed through about 100 feet of Pleistocene clay, with a little sand at the base. Below this is about 360 feet of clay, underlain by sand and containing some chert gravel, all classed with the Citronelle formation. The sands and clays at greater depths are correlated with the Pascagoula clay. These correlations are the result of a study of a set of samples of the materials penetrated.

The correlations of the formations penetrated in the Camp-Hinton Lumber Co.'s well (No. 12) are probably approximately correct, as the materials penetrated are typical of the several formations.

The well at the Natchez ice factory (No. 13) encountered about 50 feet of sand and gravel that have been assigned to the Citronelle formation and probably underlie the gravels of the Natchez formation. The underlying materials are typical of the Hattiesburg clay and Catahoula formation.

Exact correlations of the materials penetrated in the well at Bayou Sara (No. 14) are difficult. The beds in the upper 60 feet apparently belong to the alluvium of the Mississippi Valley, and the underlying sands are thought to belong to the Citronelle formation. Beneath these sands are interbedded clays and sands of the Pascagoula clay, and still lower is a thick mass of clays underlain by interbedded sands and clays, not subdivided into formations.

In western Louisiana, at Ludington, the well of the Ludington & Van Schaik Co. (No. 15) shows 150 feet of sand and gravel that belong to the Citronelle formation. Some of the older formations have been differentiated, but the log of the well below 1,600 feet is difficult to interpret.

At Fullerton the well of the Gulf Land & Lumber Co. (No. 16) encountered about 95 feet of clays containing some interbedded sand and gravel, referred to the Citronelle formation. Beneath this are more massive clay beds and some thick sands that are thought to belong to the Pascagoula clay. The massive clays below 400 feet are with some uncertainty correlated with the Hattiesburg clay.

THE FLORA OF THE CITRONELLE FORMATION.

By Edward Wilber Berry.

INTRODUCTION.

The flora of the Citronelle formation, the character of which is somewhat briefly indicated in this report, is of special interest for several reasons. It is contained in widely distributed deposits that have often been considered as forming a part of the so-called Grand Gulf formation, which recent work has shown to embrace a series of mappable units ranging in age from the lower Oligocene to the Pliocene. It is of a very recent aspect and yet it contains a considerable number of extinct types, some of which represent genera unknown in the Pleistocene or Recent floras of North America and therefore indicate Pliocene age. As practically no Pliocene plants have heretofore been recognized on this continent the present flora has an enhanced importance as a basis for future comparison. It also affords very definite evidence of the physical conditions under which it flourished.

BOTANIC CHARACTER.

Eighteen species are recognized in this preliminary contribution, a number much too small for an extended botanic analysis. The collections contain representatives of perhaps a dozen additional species, the material of which is obscure or too fragmentary for accurate determination without a very extended comparison with Recent forms. The 18 identified forms represent 15 genera, 13 families, and 11 orders. There are two gymnosperms, one monocotyledon, and 15 dicotyledons, all of which are arborescent forms. Three species—the bald cypress, water oak, and water elm—are abundantly represented in both Pleistocene and Recent floras. Fifteen species can not be identified with Recent or Pleistocene forms and are therefore considered extinct. The flora as represented is, with three exceptions, an assemblage closely resembling those to be found at the present time along the south Atlantic and Gulf coast. The three exceptions are not out of place in this assemblage but simply represent types no longer found in this immediate area. They include a species of water chestnut (Trapa) that was abundant in the American Tertiary but is now found only in Europe and Asia; a Cæsalpinia that is now represented in the Bahamas; and a Bumelia that is now confined to the West Indies and peninsular Florida, though Bumelia is still represented by other species in southeastern North America. The remains of the bald cypress, water chestnut, and live oak are by far the most abundant in the collections, but the other oaks, the gum, and the hickory are not uncommon. The rarest remains are those of Yucca, Prunus, and Vitis. Yucca is almost never fossilized, and Vitis is usually represented by small seeds that might easily escape detection. The most closely related living species, with their ranges, are indicated in the subjoined table, and the number of species regarded as extinct that are named by prefixing *pre* to the name of the corresponding existing species shows not only the ancestral character of this Pliocene flora, but the close affiliation between it and the Pleistocene and Recent floras of the same latitude.

Fossil plants from Citronelle formation and corresponding existing species.

Pliocene forms.	Most closely related existing species.		
	Name.	Northern limit.	Southern limit.
Taxodium distichum	([a])	Delaware	Cape Romano and Mosquito Inlet, Fla.
Pinus sp	Pinus clausa Sargent	Southern Alabama	Peace Creek and Halifax River, Fla.
Yucca sp	Yucca aloifolia Linné	North Carolina	Louisiana.
Hicoria pretexana	Hicoria texana Le Conte	Eastern Texas	Eastern Texas.
Betula prenigra	Betula nigra Linné	Massachusetts	Florida and Texas.
Fagus lambertensis	Fagus americana Sweet	Ontario	Trinity River, Tex.
Quercus nigra	([a])	Southern Delaware	Cape Malabar, Fla.
Quercus catesbæifolia	Quercus catesbæi Michaux	North Carolina	Louisiana.
Quercus lambertensis	Quercus heterophylla Michaux	New Jersey	Texas.
Quercus previrginiana	Quercus virginiana Miller	Virginia	Mexico.
Planera aquatica	([a])	North Carolina	Trinity River, Tex.
Cæsalpinia citronellensis	Cæsalpinia bahamensis Lamarck.	Bahamas	West Indies.
Prunus sp	(?)		
Vitis sp	(?)		
Trapa alabamensis	Trapa natans Linné	Central Europe	Southern Europe.
Nyssa aquaticaformis	Nyssa aquatica Linné	Southern Illinois	Nueces River, Tex.
Bumelia preangustifolia	Bumelia angustifolia Nuttall	Indian River, Fla	Bahamas.
Fraxinus sp	Fraxinus floridana Sargent	Southern Georgia	Lower Apalachicola River, Fla.

[a] Still existing.

PHYSICAL CONDITIONS INDICATED BY THE FLORA.

That this flora is comparable in a broad way to the existing flora of the same region has just been pointed out. Although one of the modern representatives (*Fagus americana*) reaches northward to Ontario, it is not identical with the fossil form and, moreover, finds its optimum conditions much farther south. One other, also a form not identical with its fossil representative, reaches southern New England, but the others that range northward are forms of the southern flora, like the yucca, live oak, turkey oak, and water elm, that reach their northern limit in the Atlantic Coastal Plain, between southern Delaware and North Carolina. The species are, without exception, coastal forms, and the modern representatives of several (Hicoria, Cæsalpinia, Bumelia, and Fraxinus) do not range more than 150 miles inland from the Gulf coast. Without further elaboration, I think it will be conceded that the climatic conditions of this epoch in the Pliocene could not have been appreciably different from those of the present time in southern Alabama.

The physiography during late Pliocene time and, to a certain extent, the vegetation also, may be compared with those of Recent time along the east coast of the Florida Peninsula north of latitude 28°, or along the Gulf coast from the mouth of Ocklockonee River westward to Mobile Bay. We may picture a more or less straight series of barrier beaches, probably with active sand dunes, a mile or more in width, and broken in places by inlets. Back of these beaches there were wide lagoons, of variable width, perhaps not less than a mile and certainly reaching a much greater width where some river expanded into a broad estuary, with its shallow and muddy bayous. The water in the lagoons varied from fresh to salt according to the presence or absence of inlets and the position of the rivers. As is so common at the present time, the inner margins of the lagoons were bordered in places by lines of old, probably quiescent, vegetation-covered dunes, approximately parallel with the seaward zone of dunes. These rested on the seaward margin of the mainland or were separated from it by a narrow lagoon of fresh water or by fresh marshes or swamps. The mainland was low, flat, and alternately muddy and sandy, and had a very gentle gradient. The shallow depressions of its surface afforded a congenial environment for the development of cypress ponds or mixed tupelo gum swamps, with the associated water elm, Hicoria, and

Fraxinus, suggesting Recent conditions as exemplified by the flatwoods of eastern Florida.

Certain mesophytic genera inhabiting river banks and bottoms, such as Taxodium, Nyssa, Hicoria, Betula, Fagus, Vitis, and Planera, are preserved as fossils, while the abundantly preserved nuts of Trapa indicate that it was common in the sluggish river waters. The rivers were unquestionably sluggish and meandering. They expanded in their lower courses into estuaries or broad bayous, bordered by swamps in which grew a great abundance of Taxodium, replaced here and there by Nyssa, with perhaps a sprinkling of other mesophytic genera such as Hicoria, water oak, and Planera. The old dunes as well as parts of the barrier beaches (islands or peninsulas) supported a thick scrub of various species of live oaks and black oaks, with some pines. The single specimen of a yucca indicates the probable abundance of this xerophytic genus on the beaches and dunes, its habitat and persistent leaves fully accounting for its rarity in the fossiliferous clays. The species of Prunus, Cæsalpinia, and Bumelia probably grew in somewhat similar habitats. (See Pl. XLIV.)

The physical conditions that I have pictured are based on the two localities that have furnished fossil plants, and the preceding statement was written in the spring of 1911.[1] It is therefore of interest to confirm the essential correctness of these conclusions by quoting from Dall's report [2] on certain Pliocene invertebrates from wells in southern Georgia and Louisiana and from exposures near Burkeville, Tex. He writes:

> The interest of this fauna lies not only in its being strictly brackish water and containing a large number of hitherto unknown species, but in its wide distribution along the edge of the Pliocene Coastal Plain, forming a faunal horizon hitherto unrecognized.
>
> The conditions appear to have been not unlike those which obtain at certain portions of the Gulf coast to-day; probably lagoons into which the streams poured fresh water carrying with it small fresh-water gastropods and occasionally valves of Unionidæ. On the other hand, the sea had access to the lagoons, keeping the salinity of the water such that oysters and anomias could flourish with other smaller mollusks which frequent oyster beds, while occasionally purely salt-water shells might be ejected by wandering fishes or carried by violent storms.

[1] Berry, E. W., A study of the Tertiary floras of the Atlantic and Gulf Coastal Plain: Am. Philos. Soc. Proc., vol. 50, pp. 314-415, 1911.

[2] Dall, W. H., On a brackish-water Pliocene fauna of the southern Coastal Plain: U. S. Nat. Mus. Proc., vol. 46, p. 22, 1913.

AGE INDICATED BY THE FLORA.

The three still existing species and the similarity of the extinct forms to those of the Pleistocene and Recent would seem to indicate a relatively late time in the Pliocene. The facies as a whole is modern rather than Miocene. On the other hand, there are no known American Miocene floras nearer to this region than Virginia, and the large proportion of extinct types, much greater than in any of our extensive Pleistocene floras, would argue for a Pliocene age. This is also indicated by the abundance of Trapa, no longer native in the Western Hemisphere. The argument is further strengthened by the presence of coniferous remains, not described in this report because of their uncertain character but believed to represent the genus Glyptostrobus, which is now oriental but was common in America during the Tertiary. It is corroborated by the faunal studies of Dall previously mentioned and by the areal stratigraphic studies of Matson outlined on pages 172–173. Moreover, the flora is definitely older than that from the Mississippi River bluffs in western Kentucky,[1] which I have regarded as Pleistocene, though the beds in which it occurs are overlain by heavy gravels altogether lacking glacial materials and for that reason some students are inclined to consider them as late Pliocene rather than early Pleistocene.

My conclusion is, then, that the flora found in the Citronelle formation belongs in the later half of the Pliocene epoch and is directly ancestral to the Pleistocene and Recent floras of the same region.

THE FLORA.

Order CONIFERALES.

Family PINACEÆ.

Subfamily TAXODIINÆ.

Genus TAXODIUM L. C. Richard.

Taxodium distichum (Linné) L. C. Richard.

Plate XLV, figures 1–6.

Taxodium distichum. Holmes, Elisha Mitchell Sci. Soc. Jour., p. 92, 1885.

Taxodium distichum. Hollick, Maryland Geol. Survey, Pleistocene, pp. 218, 237, pl. 68, 1906.

[1] Berry, E. W., The Mississippi River bluffs at Columbus and Hickman, Ky., and their fossil flora: U. S. Nat. Mus. Proc., vol. 48, pp. 293-303, pl. 12-13, 1915.

Taxodium distichum. Berry, Torreya, vol. 6, p. 89, 1906; Jour. Geology, vol. 15, p. 339, 1907; Am. Naturalist, vol. 43, pp. 432–434, figs. 1, 2, 1909; Am. Jour. Sci., 4th ser., vol. 29, p. 391, 1910; Torreya, vol. 10, p. 263, 1910; Plant World, vol. 16, pp. 39–45, figs. 1, 2, 1911; Am. Jour. Sci., 4th ser., vol. 34, p. 219, figs. 1, 2, 1912; Torreya, vol. 14, pp. 160, 162, 1914; U. S. Nat. Mus. Proc., vol. 48, p. 296, 1915.

Twigs, seeds, cone scales, and cones occur at both of the known plant beds in the Citronelle formation, and one of the localities (Lambert) has yielded remains of the staminate catkins. All these parts are well shown in the accompanying figures. None of these remains can be distinguished from those of the existing species. If they represent that species they constitute the oldest known authentic remains of it, for it has not heretofore been found in deposits older than Pleistocene. This statement is seen to lack significance, however, when it is recalled that it would be a difficult task to formulate good differential characters for the very common and widespread Tertiary species *Taxodium dubium* of Sternberg; in fact, most writers refer to it as *Taxodium distichum miocenum.* Moreover, indubitable remains of the bald cypress have been recorded from the late Pliocene of Germany by Geyler, Kinkelin, and Engelhardt under the name *Taxodium distichum pliocænicum.* A subconscious desire to substantiate the Pliocene age of the Citronelle formation might dictate the reference of the Citronelle bald cypress to this supposed variety from the European Pliocene. The probabilities are, however, entirely favorable to the supposition that the forms on the two sides of the Atlantic were distinguished by features that have not been preserved, though both may have been geographic varieties of *Taxodium dubium.* It must be admitted that although possibly distinct the Citronelle form can not be differentiated from the existing species, and in any case it unquestionably represents the immediate ancestor of that species.

Turning to the geologic record we find that no fossil species of cypress have been recorded with certainty from strata as old as the Cretaceous, although it is quite possible that some of the twigs of conifers that are usually referred to Sequoia may really be those of the cypress, and the fact that some of them were deciduous might also suggest this possibility. In the earliest Eocene, however, in the days when the primitive mammalian fauna was replacing the last of the dinosaurs, the ancestors of the cypress had an almost cosmopolitan range. The records are very numerous and are based on the remains of leafy twigs, which seem to have thus early acquired the deciduous character for which their modern descendant is remarkable. Cone scales have also been found, and in some localities—for example, in Alberta, in the basal Eocene—the wood, showing the characteristic anatomical features of the genus, is preserved. For high latitudes there are Eocene records from Siberia, Manchuria, Alaska, Grinnell Land, Greenland, and Spitzbergen. From this northern area the cypress seems to have spread southward over the western provinces of Canada at least as far as Montana, Wyoming, and Nevada. For the next succeeding geologic epoch, the Oligocene, the records are rather meager if we assume that all the Arctic Tertiary occurrences are Eocene and not in part Oligocene. There are, however, a number of European records of Oligocene occurrences, including southern France and the Baltic provinces of the German Empire, from which the cypress extended eastward into Asiatic Russia. In the succeeding Miocene epoch the cypress extended from Japan on the east to Austria, Switzerland, and Italy on the west. In North America at this time the cypress was present in Virginia, on the east coast, and in Oregon, on the west coast.

For the last epoch of the Tertiary, the Pliocene, American records are lacking aside from those of the Citronelle formation, but a cypress scarcely if at all distinguishable from the still existing species was perhaps the most common denizen of the shores of the greatly extended Pliocene (Plaisancian) sea that spread over southern Europe and eastward into Asia.

The Tertiary period was followed by the climatic changes that ushered in the glacial or Pleistocene epoch. Records of Pleistocene migration are scanty, but we know that the cypress became extinct in Eurasia and that it retreated toward the Gulf region in America, perhaps oscillating southward and again northward with the advance and retreat of the ice front. The still existing form in Mexico may be a relic of such a southward migration. There are a large number of records of American Pleistocene cypress swamps based on the preserved trunks and typical knees. The peat of many of these swamps is packed with the cones and seeds, or a lens of clay may have preserved the deciduous twigs. I have collected unmistakable staminate aments from the Pleistocene clays at one place in North Carolina. On the final recession of the last ice sheet the climate became somewhat warmer than that of to-day, as is shown by certain subfossil animals and plants collected at several points from Maryland to Massachusetts, as well as by the isolated occurrence of members of the existing flora many miles to the north of their normal range. An example of this sort has been recently recorded by Sears[1] for Essex County, Mass. My own records of Pleistocene cypress include seven localities north of the present range of the species, one in New Jersey, nearly 150 miles north of the present northern limit, and one at Buena Vista, Va., west of the Blue Ridge, which forms its present northwestern limit. That these facts have more than a local significance is shown by the admirable and exhaustive studies of Scandinavian students who have conclusively demonstrated a considerable northward postglacial extension and a subsequent retreat of the existing flora. In regard to the cypress this last statement is confirmed by the subfossil occurrences which show that its range is steadily contracting.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.; Red Bluff, Perdido Bay, Baldwin County, Ala.

Collections: United States National Museum.

Subfamily ABIETINEÆ.

Genus PINUS Linné.

Pinus sp.

Plate XLV, figures 8, 9.

Large and well-defined seeds of a species of pine occur in the collections from Lambert. The wings are not preserved, but many seeds of existing species preserved in Pleistocene and subfossil deposits also lack the wings. The seeds found at Lambert are more like those of *Pinus tæda* Linné than those of any other existing species with which they have been compared, but whether they represent an existing or extinct species has not been determined.

Associated with the seeds are fragmentary but perfectly recognizable leaves of Pinus. These too have not been specifically determined. A number of the existing pines are coastal species, the loblolly (*Pinus tæda*) is of common occurrence along shores, and *Pinus serotina* Michaux is distinctly a coastal-swamp form. *Pinus clausa* Sargent, of Florida and southern Alabama, frequents beach ridges and dunes and is found on the Santa Rosa Peninsula in association with the live oak so abundantly represented in the Citronelle formation.

It has not been possible to determine whether the fossil leaves and fruit represent a species of the beach ridges or of the low coast of the mainland.

Occurrence: Citronelle formation, near Lambert, Mobile County, Ala.

Collection: United States National Museum.

Class ANGIOSPERMÆ.

Subclass MONOCOTYLEDONÆ.

Order LILIALES.

Family DRACÆNACEÆ.

Genus YUCCA Linné.

Yucca sp.

Plate XLV, figure 7.

A narrowly linear-lanceolate and acuminate distal fragment of a very rigid coriaceous entire margined monocotyledonous leaf, which constitutes the scanty remains of this form, is insufficient for a specific description, and if it occurred in beds belonging to a more remote geologic period or in a region and latitude where the possibilities of the flora were unknown no positive generic determination could be made. In the light of these contributory facts, however, it is certain that this fragment represents some species of Yucca, whether a still existing or an extinct species it is impossible to determine.

The genus Yucca contains a score or more of existing species confined to the more arid parts of the central and southern United States and Central America. They have been extensively studied in recent years by William Trelease, to whose writings the reader is referred for a discussion of the very interesting facts of their geographic distribution. The present fossil fragment agrees exactly with the leaves of *Yucca aloifolia* Linné, a form ranging on coastal sands from North Carolina to Florida

[1] Sears, J. H., A southern flora and fauna of post-Pleistocene age in Essex County, Mass.: Rhodora, vol. 10, pp. 42-46, 1908.

and westward along the eastern Gulf coast. Prof. Trelease writes in a personal letter:

Yucca aloifolia is probably of a different early stock from the other existing species, which have either capsular fruit or a dry core to the fruit when this becomes fleshy, *aloifolia* lacking such a core.

So far as I know, no indubitable fossil remains of Yucca have heretofore been discovered, so that the importance of the present occurrence, despite the meagerness of the remains, merits its discussion. The existing southeastern species are distinctly forms of sandy coastal regions, and the sands and dunes along the coast during the time of the deposition of the Citronelle formation may be appropriately pictured as supporting an *aloifolia*-like form. That its remains have not been more abundantly encountered in the deposits of this age is obvious from the foliage habit in this genus, as the leaves are persistent until they become practically desiccated, so that it would require a cyclonic disturbance or a rapid transgression of fine sediments to place them within reach of successful fossilization. That the type and only specimen is a distal part of a leaf sharply broken across merely emphasizes the preceding statement.

Occurrence: Citronelle formation, near Lambert, Mobile County, Ala.

Collection: United States National Museum.

Subclass DICOTYLEDONÆ.

Order JUGLANDALES.

Family JUGLANDACEÆ.

Genus HICORIA Rafinesque.

Hicoria pretexana Berry, n. sp.

Plate XLV, figures 10–13.

The genus Hicoria is represented by both leaflets and nuts that may indicate more than one species, although I have ventured to unite them as representing the nuts and the lateral and terminal leaflets of a single form. It may be described as follows: Leaves odd pinnate; number of leaflets not determinable. Terminal leaflet oblong-acuminate with cuneate base, nearly equilateral. Midrib stout. Secondaries numerous, subopposite to alternate, diverging from the midrib at wide angles, nearly straight in their courses, camptodrome in the marginal region, sending small tertiary branches to marginal teeth. Margins entire at base, above with small crenate teeth. Length about 10 centimeters; maximum width about 4 centimeters. Lateral leaflets narrower and more inequilateral, otherwise like the terminal; petiolules wanting. Nuts oblong-ovate in profile, bluntly pointed at both ends, slightly compressed, about 2.5 centimeters long and 1.25 centimeters in diameter, obscurely four-angled.

This species greatly resembles the existing *Hicoria texana* Le Conte, a large tree confined to the river bottoms and low wet woods of eastern Texas.

The fossil form was evidently not uncommon, as the leaflets and the nuts were found at both the fossiliferous localities.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.; Red Bluff, Perdido Bay, Baldwin County, Ala.

Collections: United States National Museum.

Order FAGALES.

Family BETULACEÆ.

Genus BETULA Linné.

Betula prenigra Berry, n. sp.

Plate XLV, figures 14, 15.

Leaves of medium or small size, broadly ovate in general outline. Apex cuneately pointed, base broadly rounded; margin somewhat irregularly crenate. Length 3.5 to 4 centimeters; maximum width 2 to 2.5 centimeters. Petiole stout, about 7.5 millimeters in length. Midrib stout, prominent on the lower surface proximad, becoming thin distad. Secondaries thin, diverging from the midrib at angles of about 45°, craspedodrome, six or seven pairs.

The present species suggests the leaves of the Pleistocene and Recent *Betula nigra* Linné, which inhabits deep, rich, often wet soils of banks, bottoms, and swamps from Massachusetts to Florida and Texas near the coast and up the Mississippi and Missouri valleys to eastern Nebraska and Minnesota. The existing birches are prevailingly north-temperate forms, *nigra* being the only species found in the warm climate of Florida, Louisiana, and Texas. It is also the only wet-ground species, as well as the only species ripening its seeds in the spring or early in summer. This character points to its derivation from a species of warm climates, such as the present fossil form. *Betula nigra* may be distinguished from *Betula prenigra* by the cuneate base of its leaf, which has a subrhombic form, and by the commonly sublobate and doubly serrate margins.

The genus Betula is widely distributed in existing floras of the North Temperate Zone from the Arctic Circle to Texas in North America and to southern Europe, the Himalayas, China, and Japan in the Old World. About 30 species are recognized, of which about half are American. Numerous fossil species have been described, the earliest of which occurs in great abundance in the basal Upper Cretaceous (Dakota) of North America.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Family FAGACEÆ.

Genus FAGUS Linné.

Fagus lambertensis Berry, n. sp.

Plate XLVII, figure 5.

Leaves of relatively small size compared with those of the existing species, broadest midway between the apex and the base, full and rounded laterally, narrowing to the bluntly pointed tip and the similarly broadly cuneate base. Margins entire below, remotely toothed along the middle, the obscurely serrate teeth becoming more crowded distad. Length about 4.5 centimeters; maximum width about 3 centimeters. Texture subcoriaceous. Petiole short and stout. Midrib medium stout, thin on the upper surface and prominent on the lower surface of the leaves. Secondaries numerous, subparallel, craspedodrome, thin but well marked; they diverge from the midrib at angles of about 45° at regular intervals, becoming more crowded in the tip and pursuing straight ascending courses. Tertiaries not made out.

The present species is clearly distinct from the existing species. The leaves of our common American Pleistocene and Recent form, *Fagus americana* Sweet, are larger and more oblong and have acuminate tips and somewhat distant or even remote, abruptly serrate teeth. It ranges from Canada to western Florida and Texas and in the Southern States is confined to river bottoms and swamp margins. Its leaves during the Pleistocene epoch, even in the far South, were smaller than those of the Recent trees and may indicate an approach to the present fossil species.

The genus includes four living species of the North Temperate Zone—one in southeastern North America, one in Europe, and two in eastern Asia. A great many fossil species of Fagus have been described, and the oldest known was found in the Upper Cretaceous of both Europe and America. The genus had a much wider distribution during the Tertiary than at present and was practically cosmopolitan, being found in association with the related genus Nothofagus of the Southern Hemisphere in Australia, South America, and Graham Land. *Fagus lambertensis* is the first Pliocene beech to be recorded from North America, but several Pliocene forms are abundant throughout central and southern Europe, and the genus has also been found in beds of this age in Japan.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Genus QUERCUS Linné.

Quercus previrginiana Berry, n. sp.

Plate XLVI, figures 1-8.

Leaves of variable size; elliptical, oblong elliptical, or obovate, ranging from long and narrow to short and broad. Apex evenly rounded, narrowly pointed, emarginate or retuse. Base rounded to narrowly cuneate. Margins entire, commonly revolute, evenly rounded, or in part irregularly rounded or incipiently sinuate. Length from 2.5 to 7 centimeters; maximum width, at or above the middle, from 1 centimeter to 2.5 millimeters. Texture very coriaceous. Petiole relatively long and very stout, ranging in length from 3 millimeters in very small leaves to 1 centimeter in larger leaves. Midrib stout, sometimes flexuous, prominent on the lower surface of the leaf. Secondaries numerous, stout, prominent on the lower surface, diverging from the midrib at various angles, usually wide, from 45° to 75°; they range from opposite to alternate, but are prevailingly opposite or subopposite; they diverge at irregular intervals and are predominantly straight in their courses but become camptodrome in the marginal region. The tertiaries are well defined, particularly on the lower surface of the leaf, where they form a minute isodiametric areolation, well shown in figures 5 and 7. On the upper surface their degree of representation gives a more open and strikingly different appearance, as may be seen in the upper surfaces shown in figures 1, 3, and 4.

This species is unquestionably close to and prenuncial of the Pleistocene and existing species *Quercus virginiana* Miller—in fact, leaves of the latter may be found which almost exactly match all the variations shown in the live-oak leaves found in the Citronelle formation. The variations in the leaves of *Quercus previrginiana* are regarded as an indication of their synthetic character; the similar variations in the leaves of *Quercus virginiana* are regarded as atavistic characters.

In the existing flora *Quercus virginiana* is a relatively short, massive, spreading tree ranging from Virginia to northeastern Mexico. It is confined to the Coastal Plain and never grows naturally far from the coast except in Texas, where it extends up the Rio Grande to the New Mexico border. It reaches its maximum development along the southern Atlantic and eastern Gulf coasts in rich hammocks but is equally at home on low sandy ridges and on old dunes. It has been recorded from Pleistocene deposits near Columbus, Ky.,[1] near Monroeville, Ala.,[2] and at Abercrombie Landing, Ala.,[3] and appears to have frequented an environment exactly comparable with its present habitat.

Associated with *Quercus virginiana* in the existing flora are a number of species or varieties that have had a common origin. Among these are the dwarf varieties *minima* and *maritima* and the recently differentiated *Quercus geminata*. Somewhat more removed are *Quercus laurifolia*, *Q. chapmani*, *Q. myrtifolia*, *Q. brevifolia*, and *Q. oblongifolia*. Some of these may be regarded as specialized for particular habitats and perhaps derived from *Quercus previrginiana;* for example, *Quercus oblongifolia*, a denizen of arid foothills and mesas in western Texas, northern Mexico, and southern Arizona and New Mexico; *Quercus breviloba*, of inland limestone prairies from central Alabama to Texas; *Quercus chapmani*, of coastal pine barrens from South Carolina to Florida; and *Quercus myrtifolia*, of seashores and dunes from South Carolina to Florida. The willow oaks *Quercus phellos*, *Q. brevifolia*, and *Q. imbricaria*, if they have diverged from a common stock with *Quercus previrginiana*, did so at a far more remote period. The correlative range of some of these forms and their restricted habitats within the general range lend weight to the hypothesis that some of them at least had a common and not remote ancestor, and it is partly a consideration of these probable facts together with minor differences that has led me to differentiate the Citronelle live oak from the existing *Quercus virginiana*, for even if it does not represent the original stock from which *Q. virginiana*, *Q. geminata*, *Q. breviloba*, *Q. chapmani*, and *Q. myrtifolia* have been evolved it certainly is ancestral to the first two and it is not far removed from the ancestor of the last three.

Quercus previrginiana is exceedingly abundant at the Lambert locality and less common at Red Bluff, where, however, all forms of its leaves are represented, so that there is nothing to indicate that it was not equally abundant at both localities in late Pliocene time.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.; Red Bluff, Perdido Bay, Baldwin County, Ala.

Collections: United States National Museum.

Quercus catesbæifolia Berry, n. sp.

Plate XLVI, figures 12, 13.

Leaves large, deeply divided by rounded open sinuses into five oblong lobes with straight sides, acutely pointed and with a subordinate acute tooth on either side toward their tips, especially in the terminal lobe. Base entire, broadly cuneate, inequilateral. Petiole short and stout. Midrib stout, prominent, and curved. Secondaries stout, diverging at various angles, those forming the median vein of lateral lobes or running to marginal teeth stouter than their fellows and craspedodrome, the rest of the secondaries camptodrome. Tertiaries largely percurrent. Texture coriaceous.

The present species is very close to the existing *Quercus catesbæi* Michaux, which ranges from North Carolina along the coast to eastern Louisiana on dry, barren sandy ridges and reaches its largest size in tidewater South

[1] Lesquereux, Leo, On some fossil plants of recent formations: Am. Jour. Sci., 2d ser., vol. 27, p. 364, 1859.

[2] Berry, E. W., Additions to the Pleistocene flora of the Southern States: Torreya, vol. 14, p. 161, 1914.

[3] Berry, E. W., Pleistocene plants from Alabama: Am. Naturalist, vol. 41, p. 693, pl. 1, fig. 2, 1907.

Carolina and Georgia. The existing species is common on the barren hills of Maubila Ridge, which forms the divide between Mobile and Escatawpa rivers and is made up of sediments of the Citronelle formation.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Quercus lambertensis Berry, n. sp.

Plate XLVI, figures 9, 10.

Leaves of various sizes, equally pointed at the apex and base, consisting primarily of a large triangular cuneate terminal lobe, a corresponding cuneate base and one or two slightly developed median lateral lobes on each side. Lobes all acute but not produced. Intervening sinuses open and rounded. Petiole short and stout. Midrib stout, usually curved. Secondaries numerous, stout, diverging at wide angles, all camptodrome except one or two median pairs, which are more prominent and run to the tips of the lateral lobes (craspedodrome). Texture coriaceous.

The smaller leaf figured well illustrates the characteristic form of this species. Although its small size and undeveloped lateral lobes suggest the juvenile leaves of several existing species of Quercus, the large and unquestionably mature leaves are represented by numerous imperfect specimens which show that these juvenile characters persisted throughout life. I have seen small leaves of the turkey oak (*Quercus catesbæi* Michaux) that resembled the fossil, and the leaves of the little-known species *Quercus heterophylla* Michaux, which by some botanists is considered a hybrid between *Q. phellos* and *Q. velutina*, are somewhat closer to the fossil than any other existing form. *Quercus lambertensis* is less common than the associated *Quercus catesbæifolia* but, like that species, is believed to have been an inhabitant of the dry sandy ridges near the coast.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Quercus nigra Linné.

Plate XLVI, figure 11.

Quercus nigra Linné. Berry, Jour. Geology, vol. 15, p. 342, 1907; Am. Naturalist, vol. 41, p. 693, pl. 1, figs. 3, 4, 1907; Am. Jour. Sci., 4th ser., vol. 29, p. 394, 1910.

Leaves of this species, of normal size and characteristic obovate form, have been found in the beds of the Citronelle formation, and are of exceptional interest as an indication of the antiquity of this handsome oak. The modern tree is an inhabitant of low rich woods and bottom lands. Its range is nearly coincident with the Coastal Plain from southern Delaware to eastern Texas, and it also extends up the Mississippi Valley to southeastern Missouri and western Kentucky. The species is common in the Pleistocene deposits of North Carolina and Alabama, where it is represented by both leaves and acorns. The leaves of the existing tree are remarkable for their diversity and the development of acutely lobed forms with broad bases. It is significant that the leaves from the Citronelle formation, as well as the numerous leaves from the Pleistocene, are without exception those with the obovate or slightly and roundly three-lobed broad tip and narrowly pointed base, which must therefore be regarded as the ancestral type for the species.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Order URTICALES.

Family ULMACEÆ.

Genus PLANERA Gmelin.

Planera aquatica (Walter) Gmelin.

Plate XLVII, figures 1–4.

Planera aquatica. Hollick, Torrey Bot. Club Bull., vol. 19, p. 332, 1892.

Planera aquatica. Berry, Jour. Geology, vol. 15, p. 343, 1907; U. S. Nat. Mus. Proc., vol. 48, p. 300, 1915.

Planera gmelini Michaux. Lesquereux, Am. Jour. Sci., 2d ser., vol. 27, p. 365, 1859.

The present species is very abundant in the clays of the Citronelle formation south of Lambert. All sizes of leaves are represented, and there is a close identity in the variations of size, form, and margin between these fossil leaves and those of the existing species. They range from small lanceolate and nearly equilateral leaves with finely serrate margins, 12 millimeters in length and 5 millimeters in maximum width, through various sizes to larger ovate leaves having markedly inequilateral bases and coarse crenate teeth, 4.5 centimeters in length and 2 centimeters in maximum width. Several of these varieties have been figured, and there can be no question that they are identical with the living species. The venation also is identical with that shown in the corresponding leaves of existing trees of this species.

The genus Planera is monotypic in the existing flora. Its single species, the water elm, is a small tree of swampy habitats, ranging from the valley of Cape Fear River in North Carolina along the coast to the valley of Trinity River in Texas and up the Mississippi Valley to lower Wabash River in Illinois and southwestern Indiana. It reaches its maximum development in southern Arkansas and western Louisiana.

Planera aquatica has been recorded by Hollick from the late Miocene or Pliocene sandstone at Bridgeton, N. J.; by Lesquereux from the Pleistocene of Columbus, Ky.; and by Berry from the Pleistocene of Hickman, Ky., and Neuse River in North Carolina. It evidently had a more extensive range in the late Tertiary than at the present time.

The genus appears in beds of early Upper Cretaceous age, where it is represented by four recorded species in Greenland, Marthas Vineyard, New Jersey, and North Carolina, which would seem to indicate an occidental origin. In confirmation of this supposition, the five known Eocene species are also confined to North America, the records including Alaska, Greenland, and the Fort Union and Green River formations of the Rocky Mountain province. The single known Oligocene species is European. There are two or three Miocene species, the records including Colorado, New Jersey, Virginia, Iceland, Sakhalin, Japan, and most European countries. The widespread Miocene species *Planera ungeri* Ettingshausen lingered throughout southern Europe during the Pliocene.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Order ROSALES.

Family CÆSALPINIACEÆ.

Genus CÆSALPINIA Linné.

Cæsalpinia citronellensis Berry, n. sp.

Plate XLVII, figure 6.

Leaflets of small size, elliptical to oval in general outline, with a broad, abruptly pointed inequilateral apex and a similar base. Margins entire. Texture subcoriaceous. Petiolule short or wanting. Length about 7 or 8 millimeters; maximum width, about midway between the apex and the base, about 4 millimeters. Midrib thin. Secondaries thin, three or four pairs, diverging from midrib at a wide angle and camptodrome. Tertiaries not visible.

The genus to which this species belongs contains about 40 existing species of the Tropics and subtropics of both hemispheres. It is no longer represented in the United States, although fossil forms are present in this area in Upper Cretaceous and younger beds. The genus is still prominent in tropical America, and the fossil species here described is very similar to the existing *Cæsalpinia bahamensis* Lamarck, of the West Indies.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Family AMYGDALACEÆ.

Genus PRUNUS Linné.

Prunus sp.

Plate XLVII, figure 7.

This genus is represented by a characteristic large stone, which is ovate, compressed, and apiculate, about 2 centimeters in length and 8 millimeters in maximum width, and rather larger than stones of our native southern species. Apparently it represents an extinct form of large-fruited beach plum.

The genus has many fossil and over a hundred existing species, which are cosmopolitan throughout the North Temperate Zone and extend to low latitudes in North America and Asia.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Order RHAMNALES.

Family VITACEÆ.

Genus VITIS Linné.

Vitis sp.

A single well-defined small seed of Vitis, not specifically determinable, is contained in the collections from Red Bluff, Perdido Bay, Ala.

Order MYRTALES.

Family HYDROCARYACEÆ.

Genus TRAPA Linné.

Trapa alabamensis Berry.

Plate XLVII, figures 9, 10.

Trapa alabamensis. Berry, Torreya, vol. 14, p. 107, figs. 4, 5, 1914.

Coriaceous nuts, rhomboidal and roughly bilateral in outline, much swollen and tuberculated medianly, with normally two short, conical, acuminate, slightly recurved horns. The base is rounded and shows a conspicuous scar. The sides are somewhat unsymmetrical and faintly and irregularly ribbed and usually show three large tubercles on each face above the middle. The base is large and full. The apex is but slightly produced or truncated. Length from tip to tip of the horns about 4 centimeters; height about 2 centimeters.

Trapa alabamensis Berry is very close to the existing *Trapa natans* Linné, especially to the two-horned variants (the species is normally four-horned). *Trapa natans* is larger and more symmetrical and has stouter, more recurved horns, a more extended apex, and a stouter and more symmetrical body. The present species is common in the late Pliocene clays of southern Alabama and was evidently very common in the slow-flowing streams and bayous that emptied into the lagoons along the low Pliocene coast.

The genus Trapa, formerly included in the family Onograceæ, is now made the type and only genus of the Hydrocaryaceæ (Trapaceæ Dumort, 1827). There are three existing species, all aquatics and all confined to the Old World except for the naturalization of *Trapa natans* Linné in New England and New York. *Trapa natans* is irregularly scattered throughout central and southern Europe, and that its area of distribution is contracting is shown by its occurrence in postglacial deposits at very many localities beyond its present range in Russia, Finland, Sweden, and Denmark. The two other existing species are *Trapa bicornis* Linné and *Trapa bispinosa* Roxbury, of southeastern and southern Asia.

The genus has an extended geologic history. Rosettes supposed to represent the floating leaves (*Trapa? microphylla* Lesquereux and *Trapa? cuneata* Knowlton) are widespread in the Rocky Mountain province in beds of late Cretaceous and early Tertiary age. The oldest recognizable fruits are a large bicornute form from the Eocene of Canada and Alaska and *Trapa wilcoxensis* Berry, from the lower Eocene (Lagrange formation) of Tennessee. An Oligocene species (*Trapa credneri* Schenk) has been recorded from Saxony, and no less than five Miocene species have been described—one in Japan and the rest in Europe, where two species continue into the Pliocene. The existing *Trapa natans* has been found in the preglacial beds of England and Saxony and in many interglacial and postglacial deposits in Portugal, Italy, Netherlands, Germany, Sweden, Russia, and Denmark, Gunnar Andersson in a recent paper (1910) mentioning 18 localities in West Prussia, 6 in Denmark, 17 in Sweden, and 29 in Finland. Trapa evidently became extinct in the Western Hemisphere soon after the close of the Pliocene epoch, for it is not a native in the existing flora (it is naturalized in New England and New York), nor has it been recorded from the Pleistocene.

Occurrence: Citronelle formation, Red Bluff, Perdido Bay, Baldwin County, Ala; Lambert, Mobile County, Ala.

Collections: United States National Museum.

Order UMBELLALES.

Family CORNACEÆ.

Genus NYSSA Linné.

Nyssa aquaticaformis Berry, n. sp.

Plate XLVII, figure 8.

Large stones, ovate-lanceolate in profile, nearly circular in cross section, rounded proximad and somewhat gradually narrowed and sharply pointed distad, 2.75 to 3 centimeters in length and slightly over 1 centimeter in maximum diameter below the middle, ornamented with about 12 thin longitudinal, sharply keeled ridges 1 to 2 millimeters in height.

This very characteristic Nyssa stone is common in the Citronelle formation. Among recent forms it is similar to the stones of the common cotton or tupelo gum, a denizen of swamps and bayous near the coast from the Dismal Swamp in Virginia through the Gulf States to Nueces River in Texas and northward up the Mississippi to the lower part of the Ohio River valley. The genus comprises five existing species in southeastern North America and one in southeastern Asia. Although some of the American species extend northward to New York and southern New England, their center of distribution is in the Georgia region. The genus is known from the Upper Cretaceous onward and was evidently cosmopolitan in the Northern Hemisphere during the Tertiary period.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.; Red Bluff, Perdido Bay, Baldwin County, Ala.

Collections: United States National Museum.

Order EBENALES.

Genus BUMELIA Swartz.

Bumelia preangustifolia Berry, n. sp.

Plate XLVII, figure 11.

Leaves obovate-spatulate in outline, with a broadly rounded tip, narrowing rapidly below the middle to a narrow, considerably decurrent base. Margins entire. Texture coriaceous glabrous. Length about 4 centimeters; maximum width above the middle about 2.5 centimeters. Petiole short and stout. Midrib very stout and prominent. Secondaries numerous, thin, subparallel, diverging from the midrib at wide angles, rather straight in their courses and camptodrome in the marginal region. Tertiaries thin, close-set, percurrent at nearly right angles to the midrib.

The present form, which is not abundant in the collections, resembles the leaves of the existing *Bumelia angustifolia* Nuttall in a great many particulars. The latter is a small evergreen shrubby or arborescent form occurring along the coast of the lower half of peninsular Florida and on the keys and the Bahama Islands. It is also said to occur in the lower part of the Rio Grande valley, so that the present late Pliocene form, which was found in an intermediate situation, may indicate that a closely allied ancestral form was common along the Gulf coast in pre-Pleistocene time. The fossil, which is described as a new species, is very close to the existing species, differing merely in its more decurrent base and more prominent venation. Some of the leaves of the modern species almost exactly match the fossil, but many of them are much narrower and relatively more elongated. They may be regarded as variants from the type prevailing during Pliocene time. It would do very little violence to the facts to consider the Citronelle form identical with the existing species, but in view of the foregoing considerations it is believed to be wiser to regard it as prenuncial.

The genus Bumelia includes about a score of existing species that are confined to America, ranging from the southern United States through the West Indies and Central America to Brazil. It includes also numerous fossil species of which the oldest comes from the Upper Cretaceous (Dakota sandstones) of the western interior. In addition to the six American lower Eocene species, which are the prototypes of still existing forms, these are two Eocene (Ypresian) species in southern England. There are about a dozen Oligocene species, ten of which are widespread in Europe, one is found in the Apalachicola group of western Florida, and two, represented by both leaves and fruit, are found in the Vicksburg limestone of Louisiana and Texas. Seven or eight Miocene species are widely distributed in Europe and one is recorded from the late Miocene of Colorado (Florissant lake beds).

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Order GENTIANALES.

Family OLEACEÆ.

Genus FRAXINUS Linné.

Fraxinus sp.

Plate XLVII, figure 12.

Small and poorly preserved leaflets of Fraxinus are contained in the collections from Lambert. The material is not extensive enough for specific determination, but its resemblance to the leaves of the water ash of Georgia and Florida (*Fraxinus floridana* Sargent) suggests comparisons with that species, to which the fossil species is clearly related. The leaflets are oblong-acuminate in outline, being widest near the middle and tapering almost uniformly both proximad and distad. Margins entire below, serrate above.

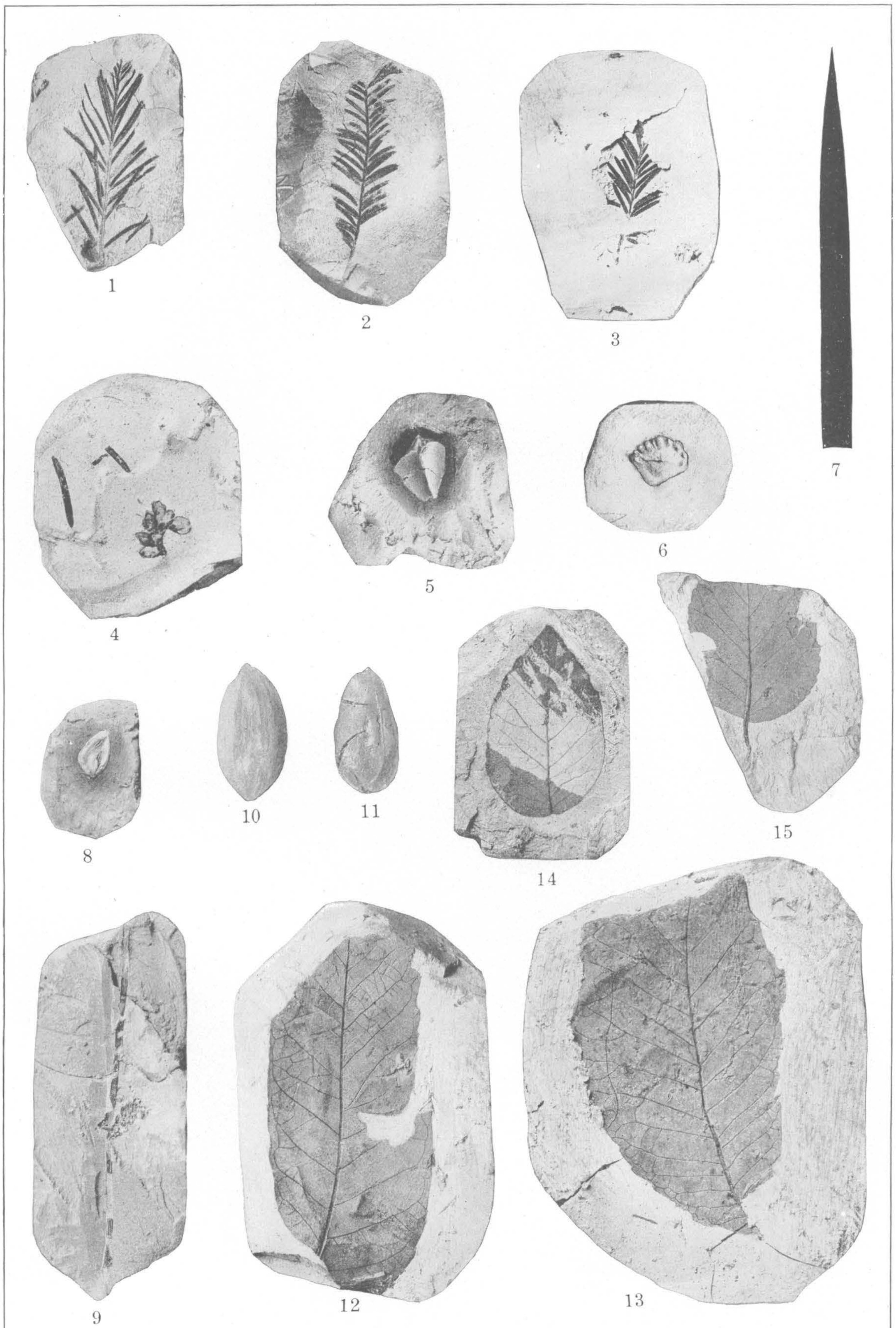
Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

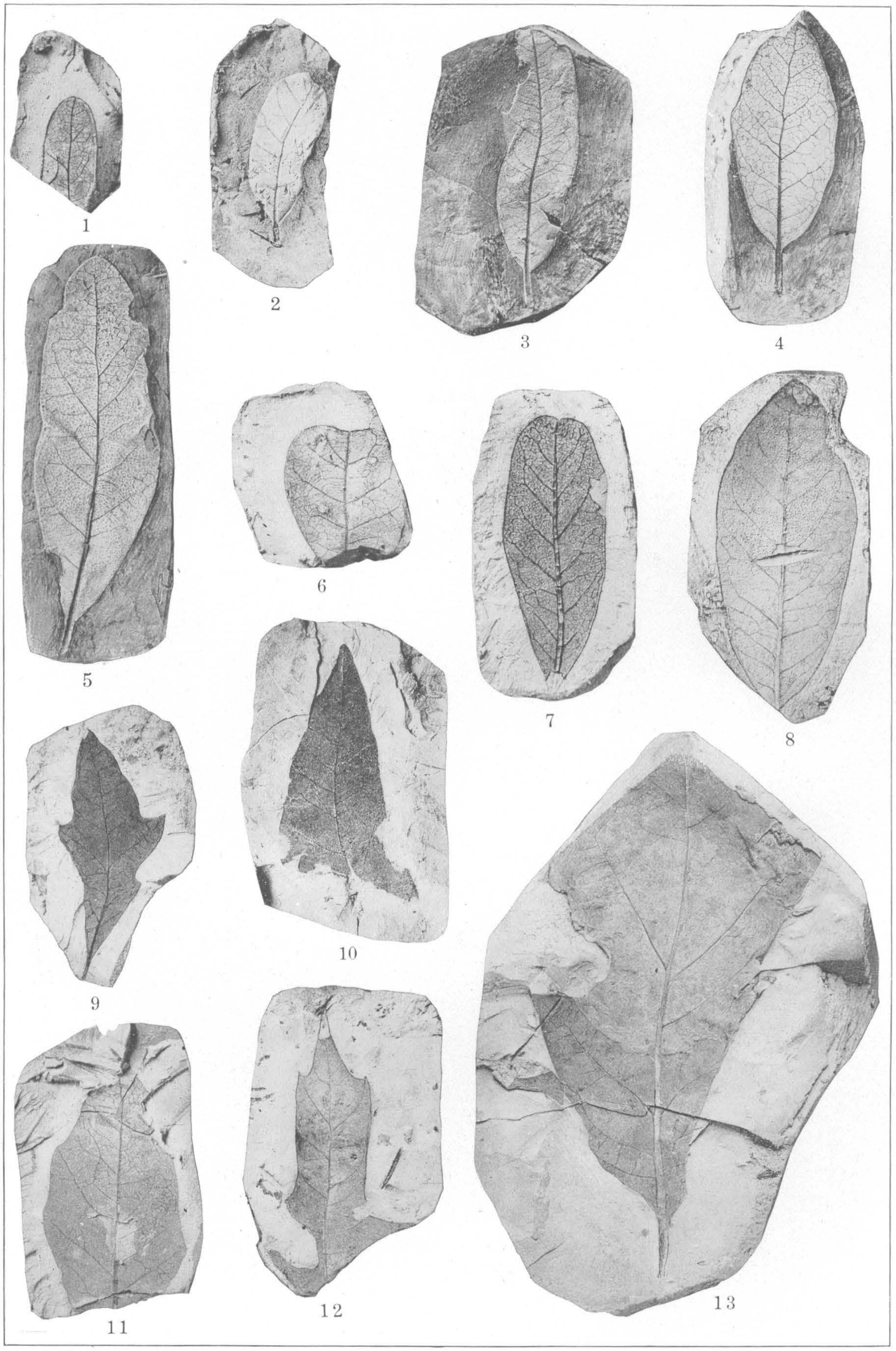
PLATES XLV-XLVII.

PLATE XLV.

All collected at Lambert, Ala.



FLORA OF THE CITRONELLE FORMATION.



FLORA OF THE CITRONELLE FORMATION.

PLATE XLVI.

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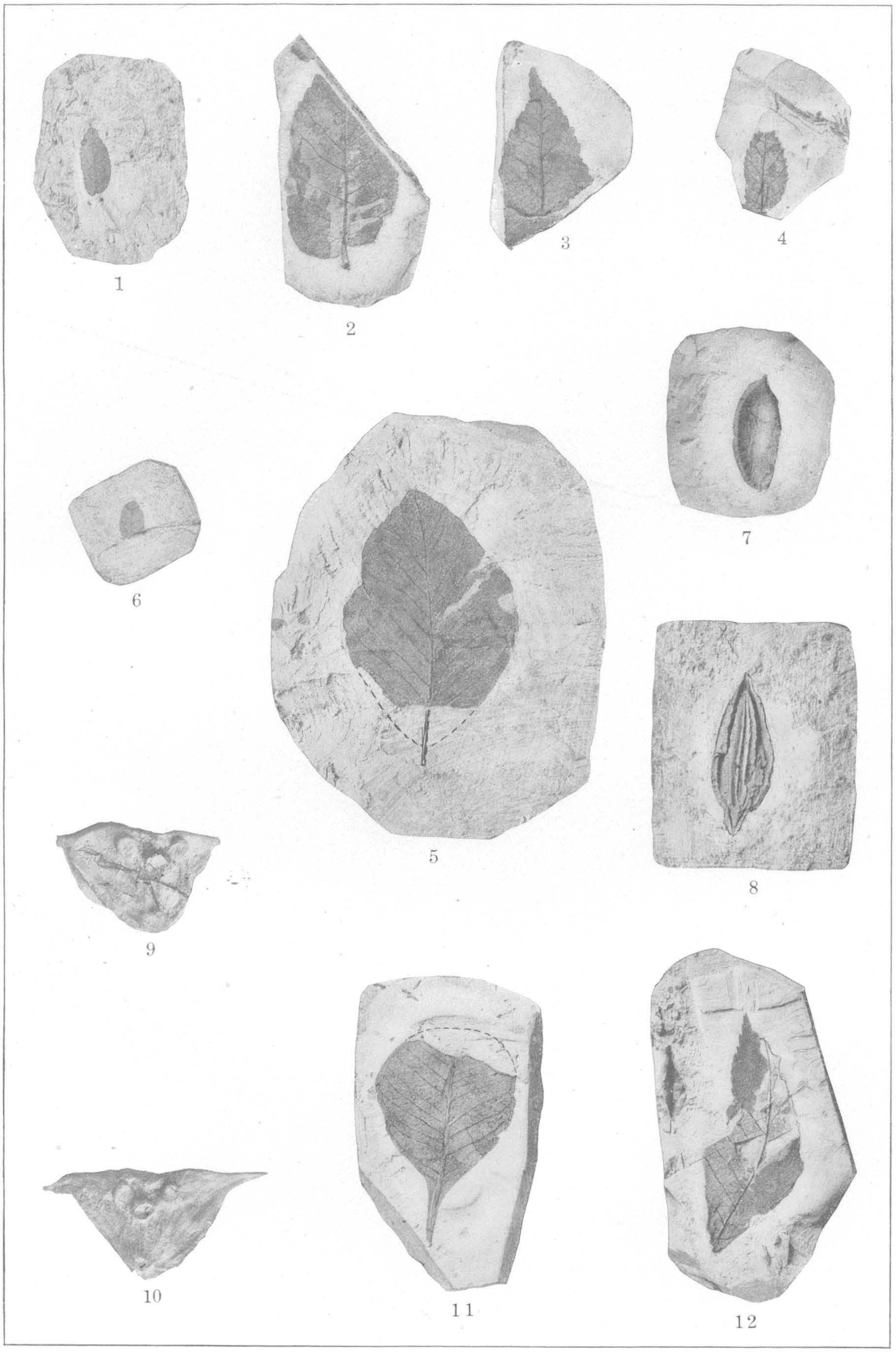
All collected at Lambert, Ala.

PLATE XLVII.



FLORA OF THE CITRONELLE FORMATION.

THE CATAHOULA SANDSTONE.

By George Charlton Matson.

DEFINITION OF THE FORMATION.

The name Catahoula was first used in 1905 by Veatch[1] as a synonym for "typical Grand Gulf," but the description of the formation, which is here quoted, was not published until the following year.[2]

Overlying the fossiliferous Vicksburg clays and limestones is a series of sandstones and greenish clays which are generally quite different, lithologically, from any of the older beds of the Tertiary series in Louisiana and Arkansas. The sandstones which are the characteristic feature of this formation range in thickness from a few inches to 50 or 60 feet, and thicknesses of as much as 140 feet have been reported.[3] These sand beds are often cemented by silica into very hard quartzites, but such occurrences are essentially local, and the quartzitic beds pass laterally in very short distances into soft sandstones or even unconsolidated sands. These sandstones and quartzitic layers have resisted erosion more than the underlying clays and unconsolidated sands of the Eocene and so have formed a line of rocky hills, the Kisatchie Wold, extending across Louisiana, into Texas on the one hand and into Mississippi on the other.

These beds contain no indication of marine life, but land plants are abundant and fresh-water shells have been found in several places. The change from the conditions existing in the Vicksburg is very marked and indicates an elevation during which the region where the oceanic conditions were favorable for the growth of marine life was considerably south of the present outcrop of the formation.

These beds were observed at Grand Gulf, on Mississippi River, in Claiborne County, Miss., by Wailes, the first State geologist of Mississippi, who referred to them as the "Grand Gulf sandstones."[4] Later Hilgard[5] used the name "Grand Gulf group" to include the beds exposed in southern Mississippi between the Vicksburg and the relatively recent coastal clays (Port Hudson) and the name has been used with varying shades of meaning by different authors since that time.[6]

In view of this confusion and in order to furnish a name not likely to be misunderstood, the name Catahoula formation is used in this paper as a synonym for the "typical Grand Gulf" or the "Grand Gulf proper." This new name is from Catahoula Parish, La.,[7] which is directly across the Mississippi Valley from Grand Gulf and where there are many outcrops which are lithologically and stratigraphically counterparts of the beds of the old type locality.

Investigations made by the author in 1911 showed that the beds at the Catahoula type locality are in part the equivalent of the Chattahoochee formation and in part the equivalent of the Vicksburg limestone, and that although Veatch defined the Catahoula as of Oligocene age, he included in his maps and descriptions of the formation sandstone and quartzite of marine origin that are now known to belong to the Fayette sandstone, of Eocene age. It is proposed to restrict the name Catahoula to the nonmarine deposits (of Oligocene age) found at the type locality and to eliminate the marine Eocene sandstones and quartzitic beds with associated clays of the Kisatchie Wold, included by Veatch in his description and mapping of the formation. These sandstones and quartzites contain imprints of marine fossils, and some of the associated clays are darker and more calcareous than those of the typical Catahoula. From their relations to the typical Jackson deposits these beds are known to be of Jackson age, and they are also known to repre-

[1] Veatch, A. C., Report on the underground waters of northern Louisiana and southern Arkansas: Louisiana Geol. Survey Bull. 1, pt. 2, pp. 84, 85, 90, 1905.

[2] Veatch, A. C., Underground water resources of northern Louisiana: Louisiana Geol. Survey Bull. 4, pp. 38–40, 1906; Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 42–43, 1906.

[3] Kennedy, William, Texas Geol. Survey Third Ann. Rept., p. 63, 1892.

[4] Wailes, B. C. L., Agriculture and geology of Mississippi, pp. 216-219, 1857.

[5] Hilgard, E. W., Report on agriculture and geology of Mississippi, pp. 147–154, 1860.

[6] In this connection see the following: Smith, E. A., and Aldrich, T. H., Science, new ser., vol. 16, 1902, pp. 835–837; Idem, vol. 18, 1903, pp. 20–26; Dall, W. H., Science, new ser., vol. 16, 1902, pp. 946–947; Idem, vol. 18, 1903, pp. 83–85; Hilgard, E. W., Science, new ser., vol. 18, 1903, pp. 180–182.

[7] It may be of historic interest to note that one of the first references to the outcrops of this formation is to the exposures at Catahoula Shoals in Catahoula Parish, which were even at that early day correctly correlated with the exposures east of the Mississippi. (See Darby, William, A geological description of the State of Louisiana, pp. 45–46, Philadelphia, 1816.)

sent the eastward extension of the Fayette sandstone.

The name Catahoula formation as originally used by Veatch was intended as a synonym for "typical Grand Gulf" or the "Grand Gulf proper." The present usage makes it include that portion of the "Grand Gulf" which is equivalent to the Chattahoochee formation and the Vicksburg limestone in the western part of the Gulf embayment. It is believed that subsequent study may permit the separation of the formation into two parts, one equivalent to the Chattahoochee formation and the other equivalent to the Vicksburg limestone.

The validity of Veatch's objection to the old name "Grand Gulf" is strengthened by the recognition of beds of Vicksburg age at the type locality of the Catahoula sandstone—Catahoula Parish, La. An additional reason for abandoning the name "Grand Gulf" is that it originally included nearly all the Tertiary deposits younger than the Vicksburg limestone.

ORIGIN OF THIS INVESTIGATION.

During the spring of 1910 the writer, working under the direction of T. Wayland Vaughan, began a study of the younger Tertiary beds of the Gulf Coastal Plain. This investigation was intended to cover the Tertiary formations younger than the Vicksburg limestone, and, as originally planned, the field studies were to begin in western Florida and were to be extended as rapidly as practicable across Alabama and Mississippi, with a hasty reconnaissance on the west side of Mississippi River for the purpose of correlating the formations east of the river with the formations recognized by Veatch[1] in Louisiana.

As the work progressed it became apparent that the investigations serving as a basis for the conclusions reached by Veatch were not sufficiently thorough to permit satisfactory correlation, and the plans were enlarged to include a portion of the State of Louisiana. The field investigations were interrupted by many demands for work in other areas and were not completed until May, 1913. The preparation of the reports was still further delayed by the demands for investigations in other portions of Louisiana and Texas, so that office work was not completed until the summer of 1914.

PREVIOUS INVESTIGATIONS.

The first report mentioning the "Grand Gulf sandstone" is that by Wailes, of the Mississippi State Geological Survey.[2] This author described the typical materials found at Grand Gulf, on Mississippi River, and correlated them with what he called the Davion rock, at the place now known as Fort Adams, farther down the river. He succeeded in tracing sandstone eastward from Grand Gulf throughout the area between the Bayou Pierre and Big Black River, and eastward to the vicinity of Raymond and Mississippi Springs, though he noted the fact that the rock changes in character, becoming more uniform in texture and softer east of Grand Gulf. His description of the equivalent of the "Grand Gulf sandstone" in the vicinity of Bayou Pierre and Mississippi Springs was apparently the result of field observations, and he drew a correct conclusion concerning the continuation of this formation eastward beyond Pearl River.

The next extensive report dealing with the "Grand Gulf" was published in 1860 by Hilgard,[3] then State geologist of Mississippi. This publication gave a more comprehensive description of the "Grand Gulf sandstone," which, as in Wailes's report, was made to include the rock as far south as Fort Adams. Several excellent sections were described in detail, and the information about specific localities was unusually full. The report was evidently the result of extensive field investigations covering the entire area from Mississippi River to the eastern boundary of the State. Hilgard wished to determine the economic value of this as well as other geologic formations, and he therefore gave a large amount of time to the study of the lithology and chemical composition of the rocks included in the "Grand Gulf." He mentioned the absence of marine fossils in this formation, the general lack of calcareous materials, the wide distribution of gypsum and salt, and the presence at certain

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 42 et seq., 1906.

[2] Wailes, B. L. C., Report on the agriculture and geology of Mississippi, pp. 216–219, 1854.

[3] Hilgard, E. W., Report on the geology and agriculture of Mississippi: pp. 147–154, 1860.

localities of fossil wood and leaves. His conclusions concerning the nonmarine character of the formation appear to be in the main correct, as is also the table showing the "Grand Gulf formation," as he mapped and described it, containing representatives of geologic formations ranging in age from the top of the Oligocene Vicksburg limestone to the Pliocene. In the description of different localities Hilgard's report is an exceptionally valuable source of information to those who wish to examine the different types of sediments included by him in the formation.

After the appearance of Hilgard's report many years elapsed before field investigations were again undertaken in the areas where the "Grand Gulf formation" is exposed. In 1893 Johnson[1] described the extension of the "Grand Gulf" into Alabama and divided it into four phases, which, arranged in order from the oldest to the youngest, are (1) the Bayou Pierre phase, in which the rock is highly siliceous and in places quartzitic; (2) the Fort Adams or Ellisville phase, including the softer sandstones and dense clay; (3) the Hattiesburg phase, which is less siliceous than the two preceding and in places lignitic; (4) the Pascagoula phase, which consists of tenacious clays containing calcareous nodules and locally abounding in shells of mollusks. Unfortunately, some of the lines separating the different phases are apparently drawn diagonally across the strike and they do not separate distinct lithologic or time units. The first two phases of the "Grand Gulf," as discussed by Johnson, appear to include the Catahoula sandstone and in some places younger beds.

A report by E. A. Smith,[2] published in 1894, was confined largely to a discussion of the "Grand Gulf" and other formations in the State of Alabama, but reference was made to the classic localities of Hilgard and Wailes in Mississippi. Most of the beds in Alabama that Smith classed as "Grand Gulf" are now correlated with the formations belonging to the Apalachicola group as developed in eastern Alabama and western Florida.

[1] Johnson, L. C., The Miocene group of Alabama: Science, vol. 21, pp. 90-91, 1893.

[2] Smith, E. A., Johnson, L. C., and Langdon, D. W., Report on the geology of the Coastal Plain of Alabama, pp. 97-107, Alabama Geol. Survey, 1894.

A subsequent paper by Smith and Aldrich[3] described the "Grand Gulf" of southern Alabama and assigned to it a position in the geologic column above the Pascagoula phase of Johnson. In this discussion the "Grand Gulf" was made to include the mottled clays, sands, and sandstones resting upon the Vicksburg limestone and other clays and sands of similar appearance lying stratigraphically above some of the younger Tertiary formations. The "Grand Gulf," according to these authors, would therefore be a blanket formation of relatively recent geologic age, or, as the authors describe it:

> Our recent observations, however, of the unconformity existing between the Grand Gulf and the fossiliferous Tertiary beds in these localities, and of the occurrence of the former as surface beds southward to the very shores of the Gulf, compel us to change our views and to assign to the Grand Gulf a place in the stratigraphic column not only far above the Tertiaries exposed on the Chattahoochee and Escambia rivers, but also above any unquestioned Tertiary existing in Alabama.
>
> The evidence of the comparatively recent age of the Grand Gulf formation thus furnished by its surface distribution is confirmed and extended by the materials brought up from three deep wells bored in Mobile County, viz, one at the brewery in the city, one about 3 miles southwest of the city (the Bascom well), and one at Alabama Port on Mon Louis Island, near the southeastern end of the county.

From the foregoing quotation and the list of fossils given by these authors it is clear that they regarded the "Grand Gulf" as younger than the Pascagoula.

In discussing the paper by Smith and Aldrich, Dall[4] expressed the opinion that the beds they described comprised only the upper portion of what Hilgard called "Grand Gulf." In the same paper Dall restated his views concerning the tentative use of the term "Grand Gulf," as follows:

> In 1898[5] I was obliged to decide on some portion of the original Grand Gulf which should continue to bear the name, after deduction of beds of which the age had been determined, and fixed upon the Oligocene clays containing lignite and fossil palm leaves, the only fossils cited by Hilgard in his original description, and in my table of Tertiary horizons referred to them as "typical Grand Gulf." The beds which Messrs. Smith and Aldrich call

[3] Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 16, pp. 835-837, 1902.

[4] Dall, W. H., The Grand Gulf formation: Science, new ser., vol. 16, pp. 946-947, 1902.

[5] U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 340 and table.

"Grand Gulf" in their communication to Science are not the same but are the nonfossiliferous upper portion at the other end of Hilgard's Grand Gulf section. I have little doubt that their assumption as to the late, possibly Pliocene age of these beds is correct, though it can only be proved by further and paleontological evidence, but this decision is merely an equivalent of the ideas above cited from Hilgard and therefore not new.

The views held by Smith and Aldrich were elaborated in a later paper[1] which sums up their conclusions:

1. The Grand Gulf of "Messrs. Smith and Aldrich" is the same fossiliferous formation which Hilgard has described by that name, and not merely "the upper nonfossiliferous portion at the other end of Hilgard's section." It is the same formation which Professor Dall calls the "typical Grand Gulf" in his recent communication and which he considers Oligocene, and a remnant of the heterogeneous Grand Gulf of Hilgard. We are compelled by the facts to believe that this typical Grand Gulf is not Oligocene at all, but that it belongs about a quarter of a mile vertically above the place in the geological scale to which it is assigned by Professor Dall.

2. There is also no Miocene Grand Gulf, as Langdon's discovery has proved and as has been confirmed by other geologists who have studied the Chattahoochee-Apalachicola section. We might perhaps more correctly say there is no Miocene Grand Gulf below the horizon of the Pascagoula, if that be certainly proved to be Miocene.

3. We think our facts prove that the Grand Gulf, all and singular, occupies a place in the geological column below the Lafayette and above the Pascagoula (which is the uppermost of the Tertiary formations as yet determined along the Gulf coast). This is all we have endeavored to show, and it was the raison d'être of our first note. We do not see wherein what we have there said in any way confirms Professor Dall's "earlier determinations" and, furthermore, we think that our view of the age of the Grand Gulf is new, and not a mere equivalent of the views of any other geologist.

In a paper by Dall[2] published subsequently he restated his opinion that the "Grand Gulf" as a whole does not lie stratigraphically above the Pascagoula clay. After disclaiming knowledge based on personal observation, he cited, in support of his position, the statements of Wailes, Hilgard, Smith, Harris, and Miss Maury. The statement by Miss Maury[3] is given below.

The Grand Gulf sandstones reach their eastern limit in south-central Alabama. Near Oak Grove the typical sandstone beds pass beneath the Oak Grove sand, indicating that the sandstone is approximately of the same age as the Chattahoochee.

Dall[4] divided the "Grand Gulf" into "typical Grand Gulf," the equivalent of the lower part of the Chattahoochee; Ellisville phase, Grand Gulf (?), represented in the upper part of the Chattahoochee; beds in Alabama and Georgia corresponding to the Chipola marl of the Apalachicola section; and the Hattiesburg phase and Oak Grove sand, equivalent to the Alum Bluff. He separated the Pascagoula from the "Grand Gulf," and his subdivisions were the same as those made by Johnson.[5]

In 1896 Vaughan[6] discussed the "Grand Gulf group" in Louisiana, and, following the classification adopted by Dall, assigned it to the upper Oligocene:

The upper Oligocene of Louisiana is represented by the Grand Gulf group of Hilgard. These rocks have been described by Hilgard, Hopkins, Johnson, and Lerch. They are composed of clays, sands, claystones, sandstones, and quartzites. So far no fossils, except a few plants,[7] have been collected and determined from them, but they are referred to the Upper Oligocene because they are without doubt the same as the Grand Gulf of Mississippi, the age of which has been fixed.[8]

The literature contains many other references to this formation, but inasmuch as the classifications adopted agree with one or another of those already mentioned, it does not appear necessary to cite all these references.

The first definition of the Catahoula is found in two reports by Veatch,[9] who described the materials occurring west of Mississippi River, correlated them with the typical "Grand Gulf sandstone" at Grand Gulf, Miss., and introduced the new name because of the confusion concerning the use of the name "Grand Gulf" by some of the earlier investigators.

[1] Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 18, pp. 20–26, 1903.

[2] Dall, W. H., The Grand Gulf formation: Science, new ser., vol. 18, pp. 83–85, 1903.

[3] Maury, C. J., Comparison of the Oligocene of western Europe and the southern United States: Bull. Am. Paleontology, vol. 3, No. 15, p. 70, 1902.

[4] Dall, W. H., and Stanley-Brown, Joseph, Cenozoic geology along the Apalachicola River: Geol. Soc. America Bull., vol. 5, p. 170, 1894.

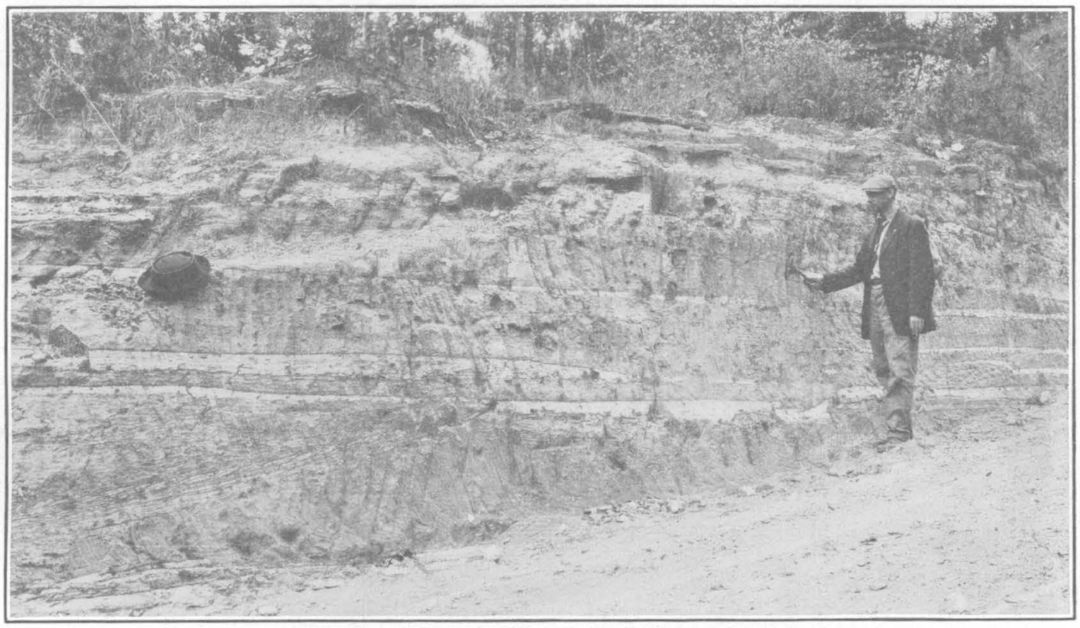
[5] Johnson, L. C., The Miocene group of Alabama: Science, vol. 21, pp. 90–91, 1893.

[6] Vaughan, T. W., A brief contribution to the geology and paleontology of northwestern Louisiana: U. S. Geol. Survey Bull. 142, p. 24, 1896.

[7] Knowlton, F. H., U. S. Nat. Mus. Proc., vol. 11, pp. 89–91, 1888.

[8] Dall, W. H., and Stanley-Brown, Joseph, Geol. Soc. America Bull., vol. 5, pp. 164, 167, 1894. Smith, E. A., Am. Jour. Sci., 3d ser., vol. 47, p. 296, April, 1894; Chart to geological map of Alabama, 1894. Dall, W. H., U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, 1898.

[9] Veatch, A. C., Underground waters of northern Louisiana and southern Arkansas: Louisiana Geol. Survey Bull. 1, pp. 84, 85, 90, 1905; Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 42–43, 1906.

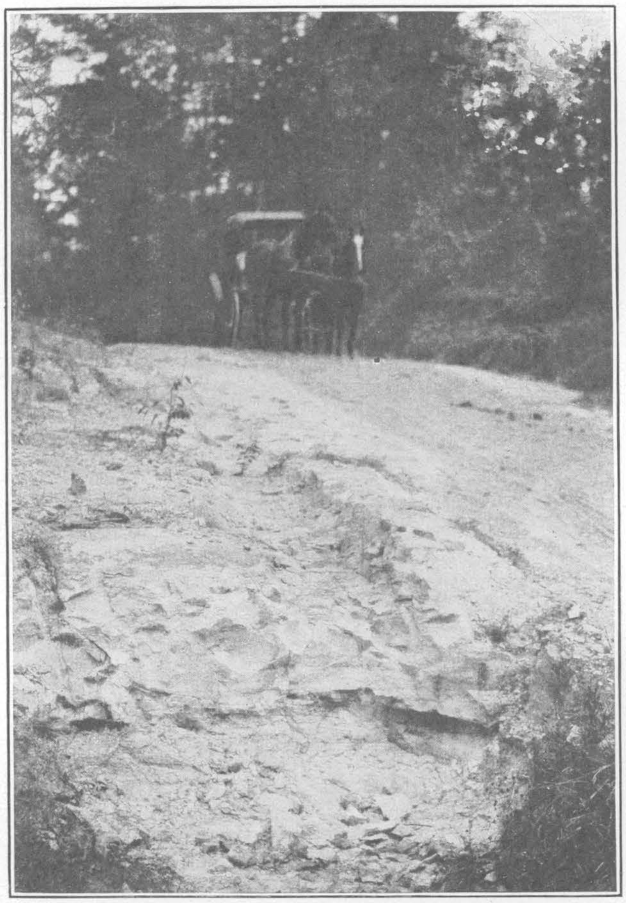


A. INTERLAMINATED AND INTERBEDDED SANDSTONES AND CLAYS.

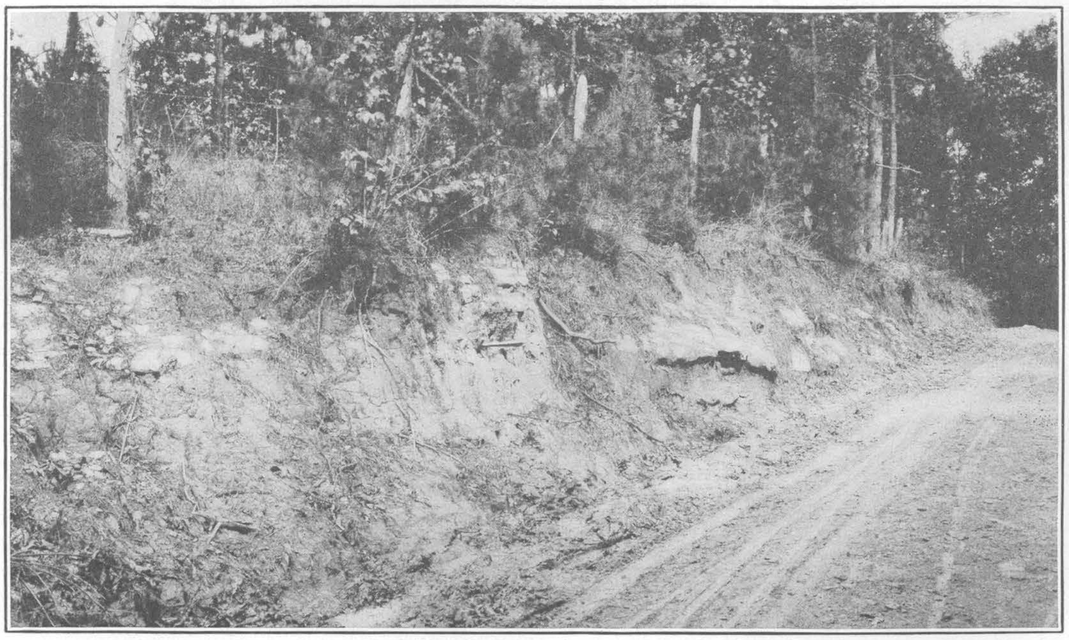
B. SANDSTONE CONTAINING IRREGULAR MASSES OF CLAY.

LITHOLOGIC CHARACTER OF THE CATAHOULA SANDSTONE.

Photographs by E. W. Shaw.



A. FINE-GRAINED SANDSTONE 3 MILES NORTHEAST OF FLORENCE, MISS.



B. WEATHERED SANDSTONE GRADING TO RED SAND, NORTHEAST OF FLORENCE, MISS.

LITHOLOGIC CHARACTER OF THE CATAHOULA SANDSTONE.

Photographs by E. W. Shaw.

Vaughan[1] presented in a recent correlation paper the following quotation from a manuscript by Alexander Deussen:

As here interpreted, the Catahoula sandstone is a lithologic and stratigraphic unit which transgresses several biologic zones. Stated differently, it is conceived to be of different ages and to have been laid down at different periods in the different regions of its occurrence. In southwest Texas it is of Claiborne age, and this kind of deposition seems to have begun in this area as early as Claiborne time. In central Texas, in the region of the Brazos, it is largely of Jackson age. In eastern Texas it is largely of Vicksburg age. According to Matson, the vertical transgression continues across Louisiana into Mississippi, where the formation is of post-Vicksburg age. This kind of deposition began in southwest Texas in Claiborne time, gradually shifted eastward, and prevailed in Mississippi as late as middle Oligocene time. If this interpretation is correct it precludes the possibility of an unconformity between deposits of Eocene and Oligocene ages in the Coastal Plain; no evidence of such unconformity has been found.

LITHOLOGY.

UNWEATHERED MATERIALS.

The Catahoula sandstone is composed of many alternations of sandstones, sands, and clays, the arenaceous sediments predominating and the argillaceous materials being distributed in more or less extensive beds of lenticular shape. (See Pls. XLVIII and XLIX, *A*.) Loose sands are comparatively rare, and interlamination of sands and clays is not conspicuous. The sandstones are commonly fine grained, and many of them contain more or less clay. Locally coarse-grained sandstones or fine-grained conglomerates are found, and the material is largely quartz, either in the form of pebbles or sand. In some of the sand the particles are so minute that the rock resembles clay. An exception to the general character of the conglomerate is found in layers of clay pebbles that have been noted in the sandstones and in the sands resulting from weathering. These clay pebbles and those formed from quartz are commonly distributed in lines parallel to the stratification of the rock, though they are in few places so numerous as to make a definite stratum themselves. In some places masses of clay a few inches in diameter occur in association with pebbles. The occurrence of clay conglomerates is not restricted to any portion of the formation, but the pebbles are scattered from top to bottom and appear to be the result of local conditions of sedimentation rather than to indicate any widespread unconformity.

Cross-bedding is general throughout the formation (see fig. 21 and Pl. LIII, *A*, p. 220), and in some places short lenses of sandstone show concentric banding. The beds are as a rule only slightly indurated (see Pl. LIII, *B*), though in a few places in western Mississippi the rock is sufficiently well cemented to be used for building stone. At Grand Gulf, Miss., near Pollock, La., and at some other localities thin layers are firmly cemented into a very dense quartzite, but rock of this type is apparently of only local occurrence. A change from slightly consolidated sands to quartzite in this formation would scarcely be expected, but it has occurred in some places where the type and quantity of mineral matter in solution in the waters furnished favorable conditions for the deposition of silica in the sands.

The sandstones and sands vary in color from gray to white, with locally a light-greenish tinge. The clays are commonly massive, more rarely interlaminated with sand, and show a tendency toward cuboidal fracture. Many of the clay beds are shown by an ordinary hand lens to contain a very large percentage of fine sand, and in some places this material is noticeable without a lens. In general the clays are somewhat sandy, though some thin beds are notably free from silica. Selenite and probably some of the amorphous forms of gypsum are in places abundant in the clays and occur in a few localities in the sandstones. Here and there rosettes of calcium carbonate occur on the surfaces of the clay layers and in the crevices where the clays are slightly broken or jointed. These rosettes have usually been regarded as accumulations of gypsum, but many of them dissolve with vigorous effervescence when placed in dilute hydrochloric acid, revealing the presence of the carbonate.

The clays of the Catahoula sandstone have a wide range in color, from light gray or white to brown or black. The dark colors are due to the presence of organic matter, either in thin laminæ or distributed in the form of particles of lignitized wood. The purer clays are pale

[1] Index to the stratigraphy of North America; U. S. Geol. Survey Prof. Paper 71, p. 790, 1912.

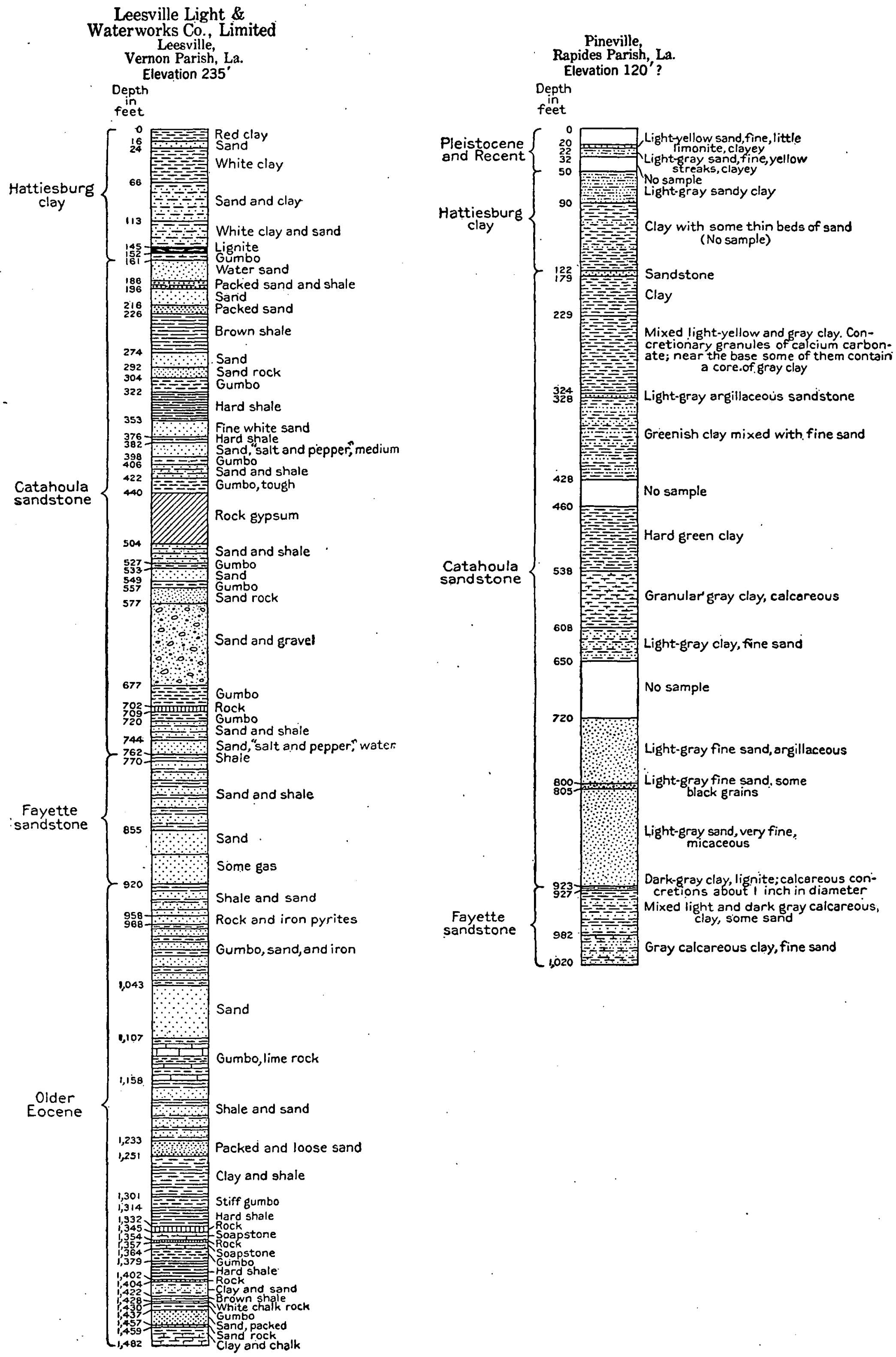
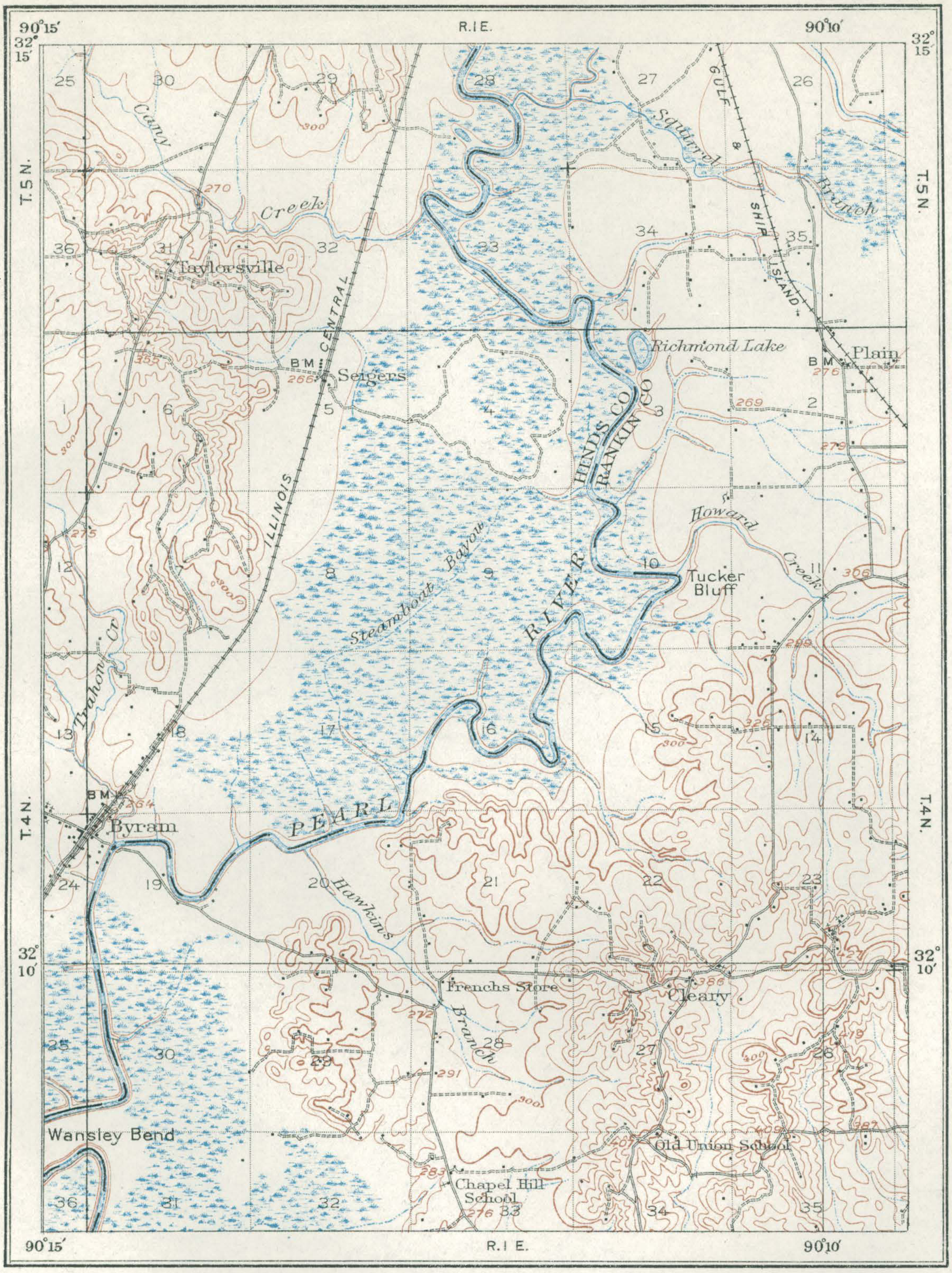


FIGURE 18.—Diagrammatic sections of the Catahoula sandstone, from logs and samples of cuttings of wells at Pineville and Leesville, La.



TOPOGRAPHIC MAP OF A PORTION OF THE FLORENCE QUADRANGLE, MISSISSIPPI

Showing the characteristic rugged topography of the Catahoula sandstone areas, the level plain developed on the underlying Vicksburg limestone, and the broad valley of Pearl River

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

blue or green when first exposed to the atmosphere, but on weathering the color changes to gray or white.

The thicknesses of the different beds in the formation are indicated in a general way by the sections in figure 18.

WEATHERED MATERIALS.

When exposed to the weather the sandstones of the Catahoula change from light gray or white to deep red or yellow, the transition commonly being effected through various stages of mottling. The change in color is in places due to the presence of grains or small nodules of iron sulphide in the form of pyrite, or marcasite, which on exposure to the moisture and oxygen of the air changes to the hydrous oxide of iron. In this process the chemical compounds which are produced exercise a disintegrating effect upon the sandstone, tending to break it down into more or less incoherent sand. During the first stages the sandstones exhibit a spotted and blotched appearance at points where the iron compounds were originally most abundant, and as the weathering progresses the color becomes a more nearly uniform red and thereafter changes gradually to orange or pale yellow. (See Pl. XLIX, *B*.) In examining beds of this sandstone it is in places possible to trace every gradation from the original light-colored rock to the final product of mature weathering, orange-colored and yellow sand. Certain peculiarities of the texture of the rock are not affected by weathering; for example, where there were layers of pebbles in the original sandstone the pebbles are arranged in a similar way in the weathered sand.

The weathering of the clays produces a more or less sandy, plastic mass of orange or yellow color, but they pass through the same stages of mottling and blotching as the sandstones. During the early stages of the process a peculiar purplish-red color is produced, though this color is not characteristic of this particular terrane but is found also in other formations, both older and younger.

PALEONTOLOGY.

Fossils are rare in the Catahoula sandstone, no remains of marine invertebrates having yet been specifically identified and only a few localities showing any trace of organic life other than lignitized wood. Fossil shells of the genus Unio have been noted in a few places, among them being areas of sandstone in the chalk hills in Louisiana, and imprints of oyster shells were found in a lens of limestone a mile east of Lena, La. At a few places imprints of leaves sufficiently well preserved to be identified have been collected, and these are described on pages 227–243 by E. W. Berry. Silicified wood is widely distributed throughout the formation, and the most common fragments are those of palm trees.

TOPOGRAPHY.

The area in which the Catahoula sandstone is exposed has been extensively eroded, the surface being reduced to slopes. The major streams have cut broad, steep-sided valleys across this formation, and their tributaries have extended their ramifications so as to drain the entire area. The principal rivers crossing the formation are Sabine River, on the western boundary of Louisiana, and the Mississippi and its tributaries, including Red River in Louisiana and Big Black, Pearl, and Chickasawhay rivers in Mississippi. In the region covered by the Catahoula sandstone there is a difference in elevation of 100 to nearly 300 feet between the levels of the streams and the heights of the neighboring portions of the upland. The accompanying topographic map of a portion of the Florence quadrangle, Miss. (Pl. L), shows the characteristic hilly topography of the Catahoula sandstone, the comparatively level plain developed on the Vicksburg limestone, and the broad valley of Pearl River, one of the principal streams in Mississippi.

The major streams have meandered enough to develop broad, steep-sided valleys across the Catahoula sandstone, and most of the valleys have been excavated below their present levels and then partly refilled with alluvium. The amount of this filling is in most places great enough to conceal the underlying Catahoula except on the convex curves of some of the meanders. Pearl River presents unusual conditions because it is partly obstructed at several places by hard layers of sandstone or clay that produce stretches of quiet water interspersed with rapids. Similar conditions are found on Red River near Alexandria, though the conditions there are explained by the fact that the river has been deflected from its old channel in recent geologic time, and a new channel has been formed across spurs of the Catahoula sandstone that project from the adjacent hills.

The northern margin of the formation is characterized by hills rising more or less abruptly above the older geologic formations. (See fig. 19.) The name Kisatchie Wold was used by Veatch [1] to designate the line of high hills in Louisiana south of the contact between the Catahoula formation, as he used the name, and the Jackson formation. Although this portion of the Catahoula of Veatch is now correlated with the Eocene Fayette sandstone, the wold is sufficiently typical of scarps produced under similar conditions to warrant description. (See Pl. LI, *A*.) This topographic feature owes its existence to the fact that the sands and sandstones of the Fayette are more resistant than the clays and marls of the Jackson formation, to the north, and consequently the softer beds have been reduced to lower levels, while the sands and sandstones remain as ridges and hills, with steep slopes to the north and gentle dip slopes to the south. The greater resistance of the Fayette sandstone is not altogether due to the fact that its beds are hard, because, even though they contain many hard layers, the sands and sandstones as a whole are friable except where they have been either case-hardened by the deposition of cementing material on the surface or cemented into irregular ledges of quartzite. Sands are usually more resistant than clays because they are less easily attacked by rain water and sheet erosion and are less readily affected by small streams such as those which do the major part of the erosive work over the large areas underlain by the formation. The sand beds therefore cap hills where they overlie formations that consist of clays and marls.

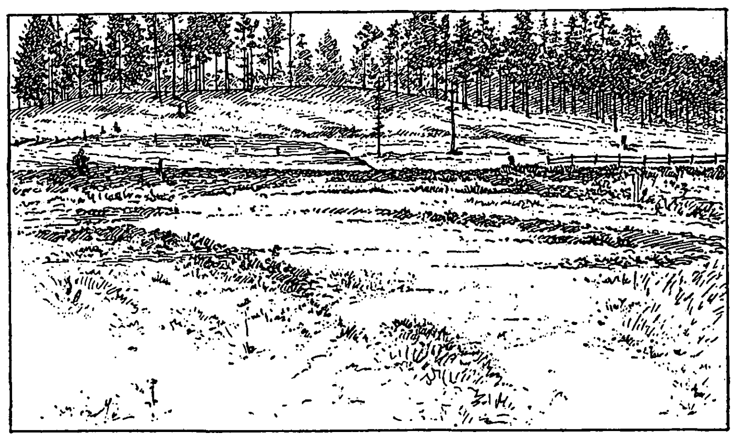
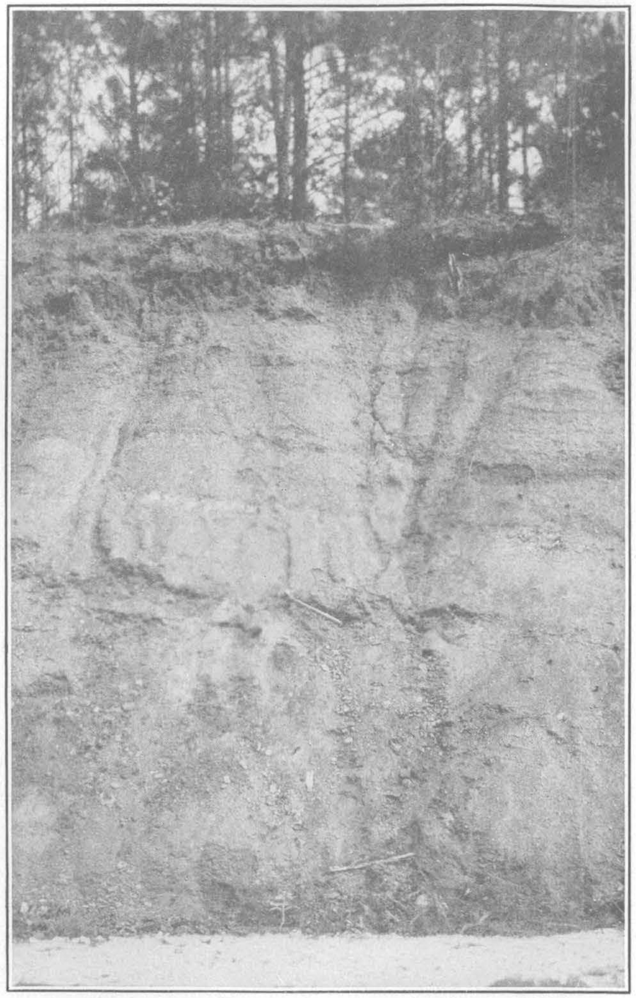


FIGURE 19.—Fayette sandstone forming northward-facing scarp of the Kisatchie Wold north of Hornbeck, La.

One of the principal reasons for the greater resisting power of porous materials, such as sand, is that water sinks readily into the pores between the grains and the amount of surface wash is thereby greatly lessened. Water enters marls and clays with much greater difficulty, but after having gained access to the upper layers it imprisons the air contained in the pores below it and, by exerting pressure upon this confined air, causes the separation of the particles and facilitates their removal by erosion. It is therefore apparent that even where a formation is composed of incoherent sand it may be expected to resist erosion more than clays or marls.

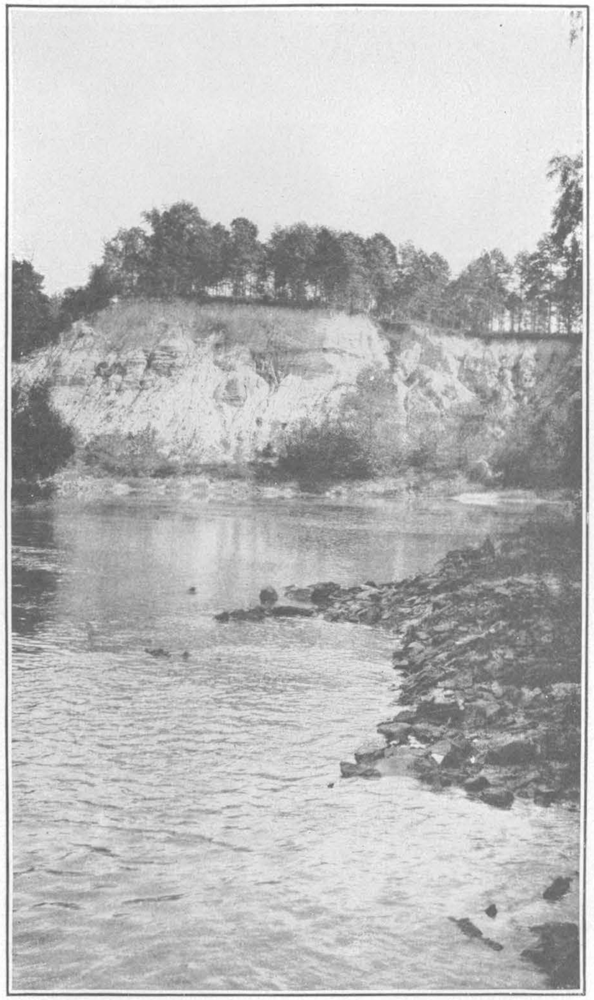
The Kisatchie Wold is less prominent east of the Kisatchie Hills in western Louisiana, but in eastern Louisiana the northern margin of the Catahoula sandstone forms a high ridge above the area to the north. The superior resistance of the sand beds causes more or less marked constrictions in the valleys where the rivers cross the formation. This is especially noticeable in the valley of Mississippi River, but the effect is accentuated because the Mississippi Valley just above the outcrop of the Catahoula sandstone is a composite of the valleys of the main stream and some large

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 15, 1906.



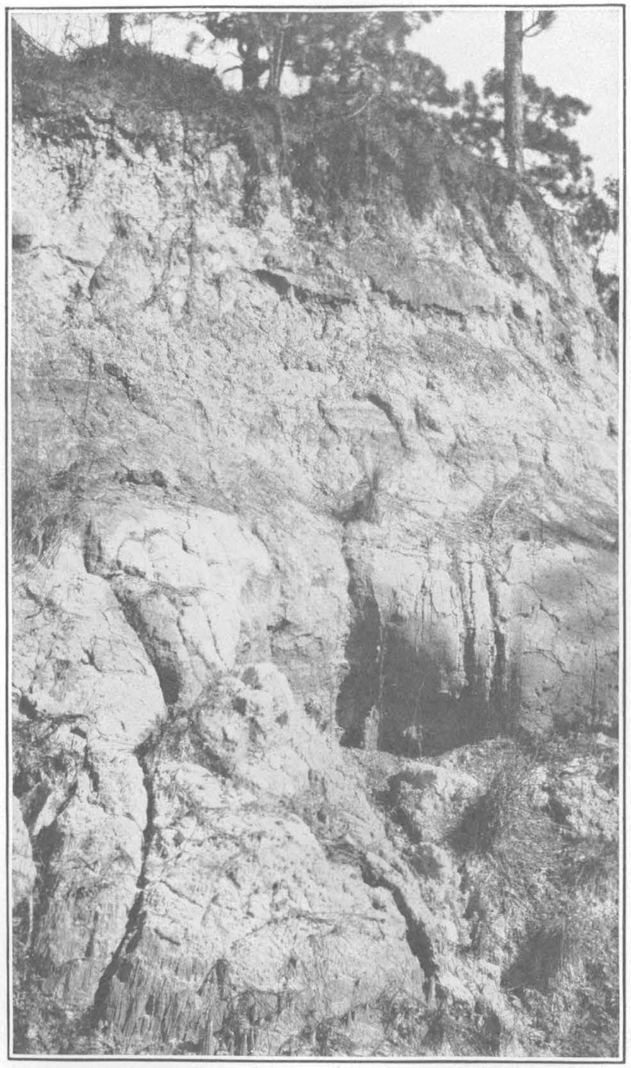
A. LITHOLOGIC CHARACTER OF THE JACKSON FORMATION.

Showing the interbedded dark clay and lenticular layers of the Fayette sandstone which form the gentle slope in the foreground of figure 19.

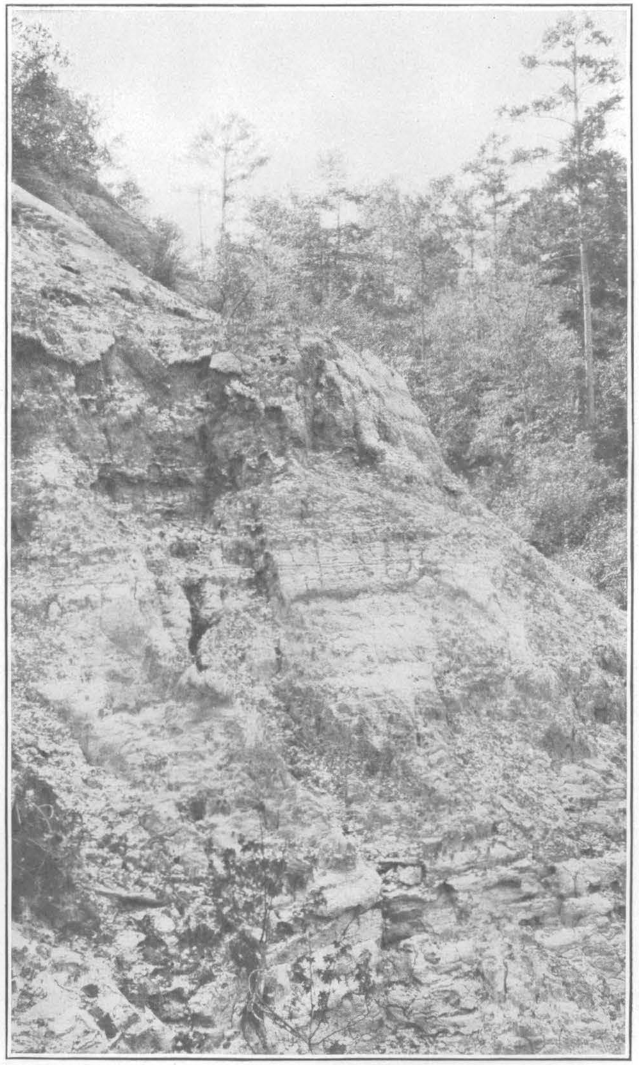


B. TOPOGRAPHIC ASPECT OF THE CATAHOULA SANDSTONE.

Showing sands and clays 3 miles southwest of Waynesboro, Miss.



A.



B.

LITHOLOGIC CHARACTER OF THE CATAHOULA SANDSTONE EXPOSED IN THE BLUFF SHOWN IN PLATE LI, *B.*

tributaries. However, the presence of the resistant sands and sandstones of this formation no doubt helped to control the points of junction of the main stream and tributaries by deflecting the tributaries. East of the Mississippi the Catahoula sandstone is less prominent topographically than in Louisiana, though it continues to form a noticeable scarp facing toward the north.

Rugged topography is found wherever the sands and sandstones of the Catahoula formation are deeply eroded, and steep slopes are produced by layers of indurated sandstones that cap hills. In many places the surface has been almost entirely reduced to slopes and the divides form long, winding ridges, but steep bluffs may be found on some of the major streams. (See Pl. LI, *B*.) The valleys of the small streams are distinctly V-shaped and the drainage has a dendritic form.

Along the northern margin of the Catahoula sandstone the streams show a tendency to follow the outcrop of the softer formations that underlie the Catahoula, but few well-defined examples of consequent drainage were noted, other than some of the small streams. One of the best examples of consequent drainage along the northward-facing scarp is Bayou Toro, a tributary of Sabine River in western Louisiana. Bayou Toro follows the north edge of the Kisatchie Wold for several miles and receives a number of tributaries from the scarp. These tributaries belong to the class known as obsequent streams and are similar to those that have developed along the landward margin of the Catahoula sandstone at many other places.

STRUCTURE.

ABSENCE OF DEFORMATION AND SALINE DOMES.

The Catahoula sandstone has undergone little deformation and presents no marked structural features. From the attitude of the sandstones gentle folds of small extent may be inferred at many places, but it is not everywhere easy to distinguish between cross-bedding on an extensive scale and inclination of beds. Because of the absence of extensive exposures, the confusion occasioned by the lenticular character of the layers, and the extent of cross-bedding, it will require a greater length of time to decipher the structure than could be devoted to this problem during the writer's general reconnaissance.

The absence of saline domes on the outcrop of the Catahoula is noteworthy when it is considered that such structures occur in Louisiana in the area north of the Catahoula sandstone, where Eocene beds are exposed, and also in the area to the south, where the Pleistocene and younger Tertiary formations overlie the Catahoula. Where the Catahoula is at the surface the absence of domes is explained by the porous and resistant character of the beds. It may be argued that the lithologic character of the formation does not furnish a satisfactory explanation of their absence, because the domes near the coast pass through the sandstones, but this argument is believed to be invalid. The formation was laid down near the strand line and it becomes much thinner and more argillaceous toward the Gulf; consequently it is represented in the belt of coastal domes by a thin deposit that should be less resistant to doming than the sandstones at the outcrop.

DIP OF THE CATAHOULA SANDSTONE.

GENERAL DIRECTION.

Local observations on the dip of the Catahoula sandstone show that there is in many places an inclination in a general southerly direction. The prevalence of these local dips indicates that the formation is not horizontal, as has been stated by Hilgard.[1]

> At their lines of contact the Vicksburg and Grand Gulf rocks consist almost throughout of lignite-gypseous laminated clays, passing upward into more sandy materials. They are not sensibly unconformable in place; but while the Vicksburg rocks show at all long exposures a distinct southward dip of some 3° to 5°, the positions of the Grand Gulf strata can rarely be shown to be otherwise than nearly or quite horizontal on the average; although in many cases faults or subsidence have caused them to dip, sometimes quite steeply, in almost any direction.

It is true that in places the sandstone dips in other directions, but the preponderance of southerly dips is noticeable in any long series of exposures like that on Pearl River.

Smith and Aldrich[2] considered the Catahoula to be a blanket formation of comparatively

[1] Hilgard, E. W., The later Tertiary of the Gulf of Mexico: Am. Jour. Sci., 3d ser., vol. 22, p. 58, 1881.

[2] Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 16, No. 142, pp. 835-837, 1902.

recent geologic age. This assumption necessitates dips of scarcely more than 200 feet in the distance between the outcrops of the formation and the inner margin of the Pleistocene formations of the Gulf coast. This distance is so great that the dip of the formation would be negligible, and the hypothesis of recent geologic age is not tenable if there is a well-defined dip toward the coast.

It is evident from the following detailed statements that the formation as a whole does not dip in a single direction. The prevalent direction of dip is southeast in central Louisiana and west of south in east-central Mississippi, the change of direction occurring near Mississippi River, where there was evidently an embayment that received the Catahoula sediments.

EASTERN LOUISIANA.

In discussing the stratigraphy along the Ouachita Harris[1] gives the dip of the Catahoula sandstone in eastern Louisiana:

> Three miles south of Danville, at Rock Hill, as has already been stated, the base of the Grand Gulf sandstone layers is 203 feet above tide. The fossiliferous Vicksburg beds in little ravines close by are from 60 to 70 feet below the sandstone layers; the intervening space is covered. Yet in the Harrisburg road perhaps 2 miles farther south thick sand beds were observed beneath the indurated ledges. These we would naturally place in the Grand Gulf stage. Ten miles southeast of Rock Hill, at Catahoula Shoals, borings made by the United States Engineers indicate the presence of hard Grand Gulf layers to a depth of 128 feet above tide. In this direction, therefore, nearly due southeast, the dip is about 31 feet per mile. If, however, we take the approximate elevation of the lower beds of the Grand Gulf just across the river from Colfax as 110 feet and note the distances and directions from each of these points and solve graphically for direction and amount of dip, we find the true dip to be S. 26° E. at the rate of 34 feet per mile.

The dip toward the southeast from Rock Hill to Catahoula Shoals as determined by Harris should have been a close approximation, but the elevation of the "hard Grand Gulf layers" at Catahoula Shoals as given by this author ("128 feet above tide") is a mistake. The boring at Catahoula Shoals did not reach the base of the formation, though it was probably not far above the base, and the bottom of this boring is reported by the Army Engineers[2] to be 186.45 feet below sea level. If the elevation of the base of the formation at Rock Hill is 60 feet less than 203 feet, as may perhaps be inferred from Harris's statement, the dip amounts to 329.45 feet in 10 miles, the distance given by Harris, or about 33 feet to the mile. The true dip may be somewhat greater or smaller, the amount of error depending on the distance between the bottom of the boring at Catahoula Shoals and the base of the formation and also on the distance between the assumed base of the formation at Rock Hill and the true base.

The base of the Catahoula sandstone on the Louisiana & Arkansas Railway 27 miles west of north from Pineville is 190 feet above sea level. A well drilled at Pineville, where the surface is 120 feet above sea level, reached the base of the Catahoula at a depth of 927 feet. The dip of the formation between these two places is therefore about 37 feet to the mile in a direction slightly east of south.

By joining the point where the base of the formation is exposed on the Louisiana & Arkansas Railway with Pineville and Catahoula Shoals the maximum dip for eastern Louisiana is found to be about 38 feet to the mile and the direction S. 24° E.

WESTERN LOUISIANA.

In western Louisiana the Catahoula sandstone has a steeper dip, but the determination is less accurate than in eastern Louisiana. The approximate position of the base of the formation at Leesville, as determined from an incomplete set of samples from a well, is 524 feet below sea level, and the base of the formation near Hornbeck is 320 feet above sea level. The distance between these places is about 16 miles, and the average dip is therefore about 53 feet to the mile in a direction east of south.

SOUTHERN MISSISSIPPI.

The base of the formation on Pearl River, in southern Mississippi, is approximately 220 feet above sea level, and in a well at Monticello it was reached at a depth of slightly less than 800 feet, or about 590 feet below sea level. The distance from the outcrop of the basal beds on Pearl River to Monticello is about 40 miles and the difference in elevation of the

[1] Harris, G. D., Tertiary geology of the Mississippi embayment: Geology of Louisiana, pt. 6, p. 29, 1902.

[2] Chief of Engineers, U. S. Army, Rept. for 1902, pt. 2, p. 1560.

base of the formation is 810 feet. The dip between these two places is therefore about 20 feet to the mile in a direction slightly east of south. Another computation based on the elevation of the base of the formation on the New Orleans Great Northern Railroad near Byram gave a result differing more than 1 foot to the mile. South of Byram the sandstone beds that occur near the base of the formation on this railroad have an elevation of 265 feet above sea level. The base at Monticello being 590 feet below sea level, the descent between the two places amounts to 855 feet. The distance between the two points is 40 miles, and this gives an average dip of 21⅜ feet to the mile, in substantially the same direction as between Pearl River and Monticello.

At Sanford the top of the Vicksburg was encountered in a well at a depth of 591 feet, or 375 feet below sea level. By joining Sanford with Monticello and with the point where the base of the formation is exposed on Pearl River, the general dip in south-central Mississippi was computed at 23 feet to the mile in a direction about 18° west of south. These figures are believed to be substantially correct, though a small amount of error in this and similar computations is to be expected because of errors in locating the exact points where the base of the formation has been observed and also because the maps used in making measurements for the computations were on a small scale and more or less inaccurate.

THICKNESS.

The Catahoula sandstone is comparatively thin in a large portion of the area where it is exposed, but in central Louisiana it may reach a maximum thickness of 800 feet. The best data for determining the thickness of the formation are afforded by samples of drillings obtained from wells. Of somewhat less value are records of materials penetrated in well

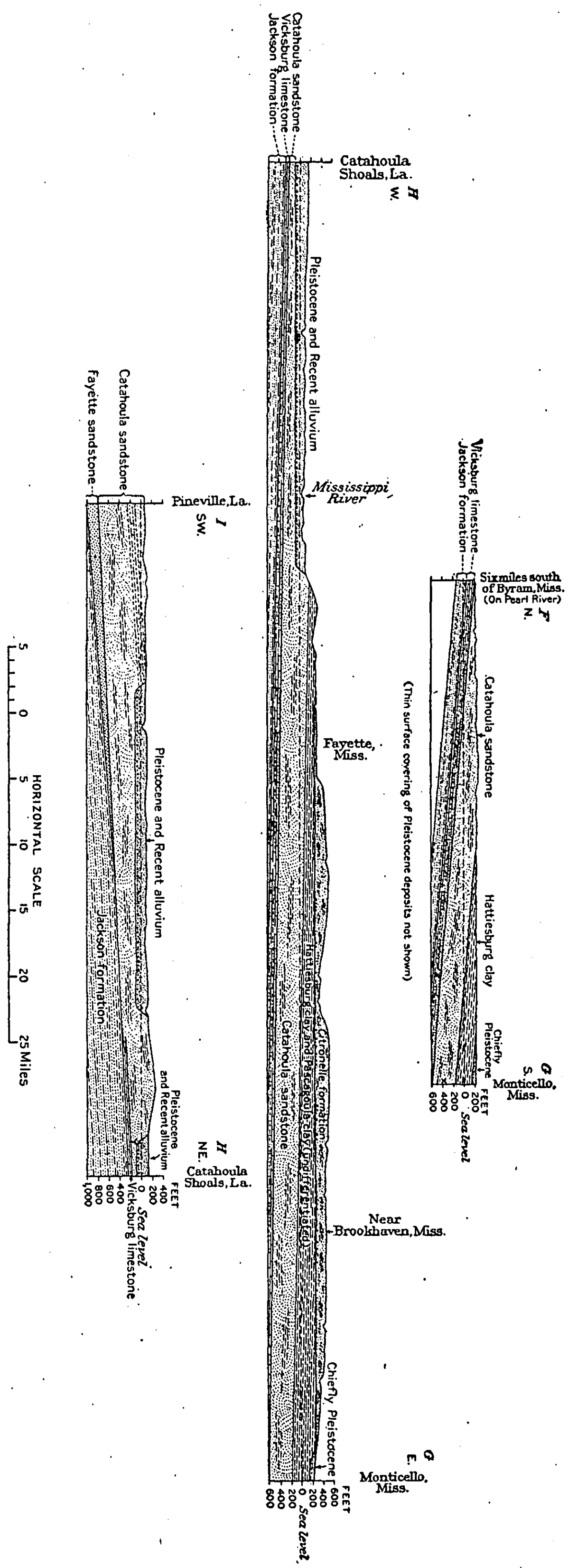


FIGURE 20.—Sections of the Catahoula sandstone. For lines of sections see figure 15 (p. 11).

borings, though where such records are carefully kept, with full descriptions of strata, the approximate limits of the formation can be recognized because it is more sandy than either the underlying or overlying beds.

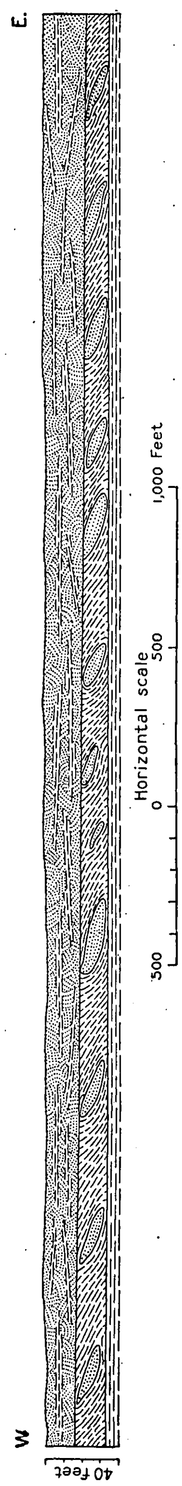


FIGURE 21.—Diagram of an exposure of the Catahoula sandstone between Chopin and Galbraith, La.

In a well at Monticello, Miss., a clay bed 300 feet in thickness overlies the Catahoula sandstone. The base of this clay lies at a depth of 380 feet, and marine shells, from their description undoubtedly Vicksburg, were encountered at about 800 feet. This gives a thickness of 420 feet. Another way of determining the thickness in this portion of Mississippi is by multiplying the rate of dip to the mile (20 feet) by the width of the outcrop in miles. This computation gives a thickness of nearly 400 feet for the formation. Farther west, near Natchez, a well penetrated 550 feet of sands, sandstones, and clays belonging to this formation.

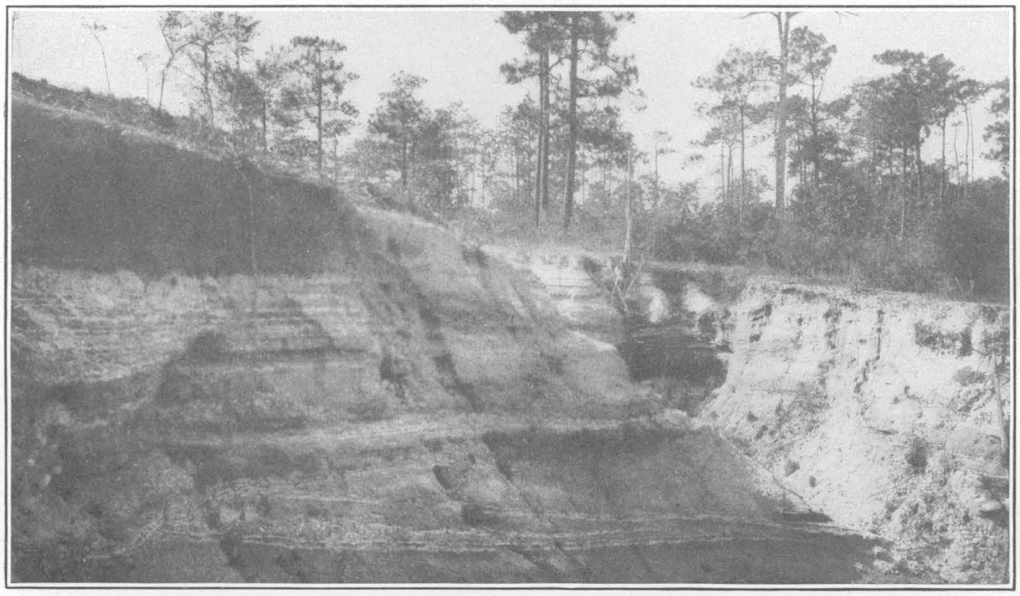
From Pearl River eastward the Catahoula sandstone thins gradually, and near Healing Springs, Ala., it is probably less than 200 feet thick, though not enough information is available to determine the full thickness in eastern Mississippi and western Alabama. West of Pearl River the Catahoula sandstone thickens, but it is not known whether the increase is at a uniform rate. In eastern Louisiana no satisfactory section giving the entire thickness of the formation could be obtained. On the assumption that the dip is uniform in this area the thickness may be computed approximately by multiplying the width of outcrop in Catahoula Parish, which is 16 miles, by the average dip, 33 feet to the mile. This gives a thickness of 528 feet, which is slightly less than the maximum thickness shown by some wells in the central part of the State.

The samples from the Pineville well, in central Louisiana, show a thickness of 800 feet of the Catahoula sandstone, though this may include a portion of the overlying Hattiesburg clay. The character of the samples indicates that the Jackson formation occupies at least 100 feet of this well section. The Catahoula is nearly twice as thick at this locality as at Monticello. The increase toward the west is due to the fact that in that area the Catahoula represents the time interval of the Vicksburg limestone. In other words, while the limestones and marls composing the Vicksburg were being formed in eastern Louisiana and east of Mississippi River, a great thickness of sandy detritus was being deposited in central Louisiana.

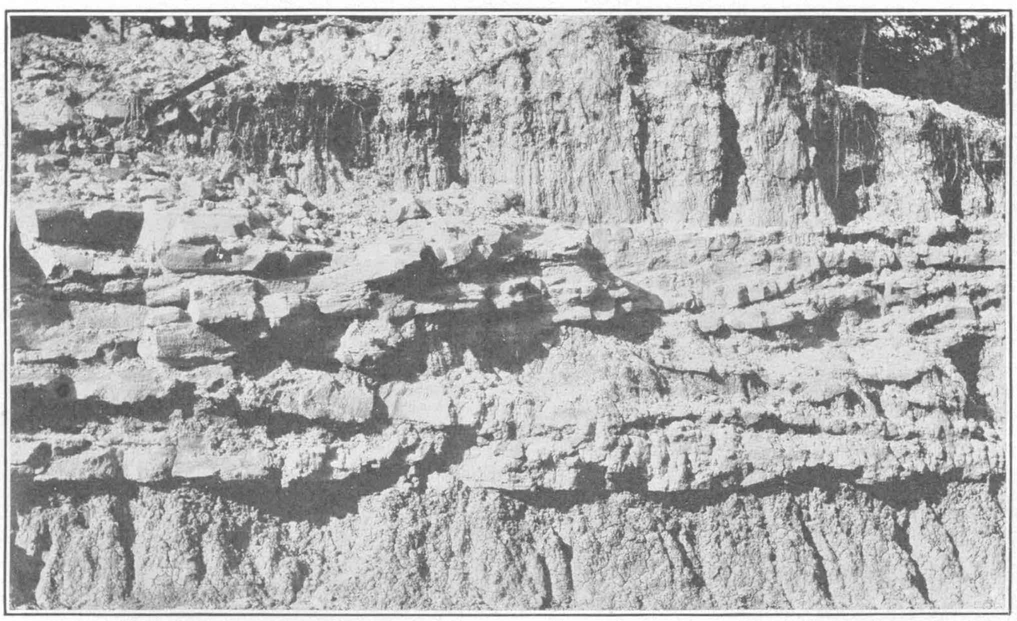
In western Louisiana and eastern Texas there is little direct information as to the thickness of the Catahoula sandstone, but it is inferred that the formation thins in that direction because the samples examined from the well at Leesville, together with the log of the well, showed a thickness of only about 600 feet of the sandstone.

ORIGIN.

All geologists who have studied the Catahoula sandstone have agreed that it is nonmarine, their conclusions being based largely on the absence of remains of marine organisms and the presence of fossils of nonmarine origin, such as leaves and a few scattered fresh-water shells of unios and anodonts, together with the character of the materials constituting the formation. The presence of a large amount of lignitized wood and numerous thin layers of lignite gives evidence of deposition in swamps, and the character of the materials themselves indicates deposition near the strand line, where there are many variations in the kinds and arrangement of sediment. (See Pl. LIII.) The formation is on the whole sandy because of the influx of swift currents bearing coarse detritus, though the presence of layers and lenses of more or less sandy clay shows that the currents were at times gentle, and, on the other hand, the occurrence of pebbles of mod-

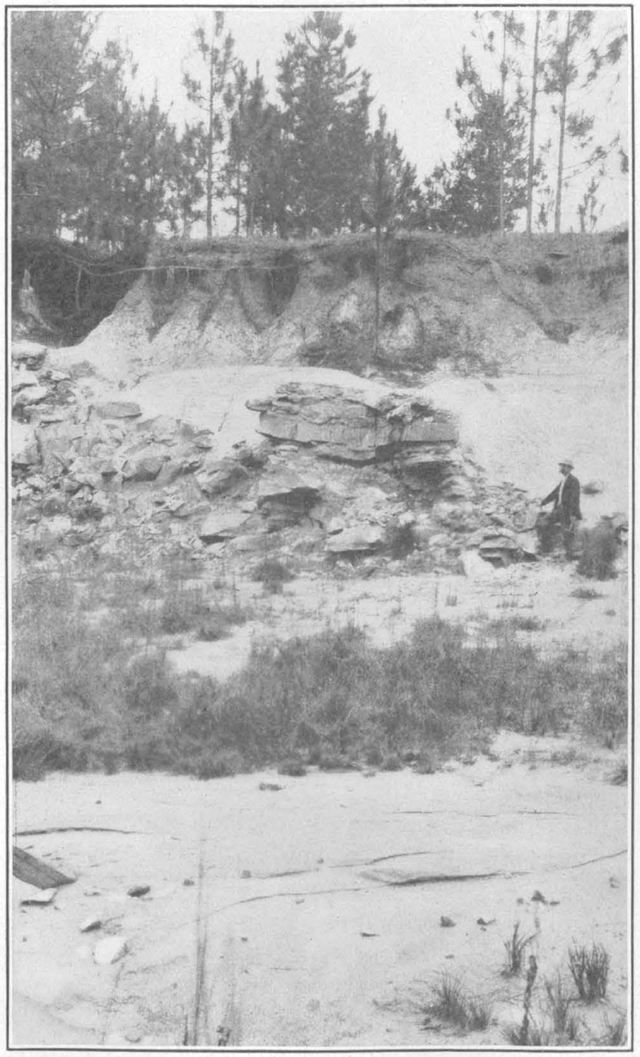


A. CROSS-BEDDED SANDS AND CLAYS, 3 MILES SOUTHWEST OF WAYNESBORO, MISS.

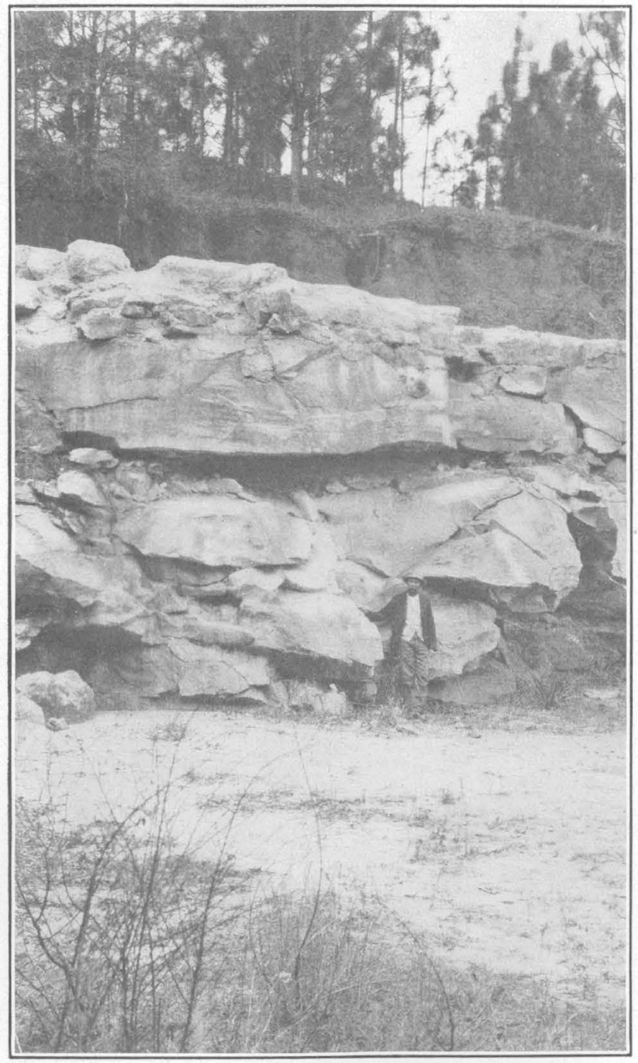


B. SANDSTONES AND CLAYS, MISSISSIPPI SPRINGS, EAST OF RAYMOND, MISS.
Photograph by O. B. Hopkins.

LITHOLOGIC CHARACTER OF THE CATAHOULA SANDSTONE.



A. LIGHT-COLORED SANDSTONE AND DARK-COLORED QUARTZITE.



B. MASSIVE BEDS OF QUARTZITE.

LITHOLOGIC CHARACTER OF THE FAYETTE SANDSTONE.

erate size in the sands indicates that at times the streams had a high velocity.

A peculiar type of bedding may be seen in one of the exposures in central Louisiana, between Chopin and Galbraith. (See fig. 21.) The upper bed consists of typical Catahoula sandstone with thin lenses of clay; the lower bed is of clay, and between these beds is a third, consisting of lenses of sand inclined steeply and separated by clay. The structure here resembles that of a delta, with the beds relatively thin and the sand lenses inclined toward the southeast away from the old shore line.

It has generally been assumed that the conditions of Catahoula time were estuarine and that the currents of water were sluggish. The theory of estuarine origin for a portion of the formation is apparently confirmed by the character of the deposits and by the fact that they contain more or less gypsum, which was doubtless deposited by evaporating saline waters. The hypothesis sometimes advanced that the currents of water entering the estuary were sluggish does not appear tenable, for the formation is made up largely of coarse sediments, though marked fluctuations are indicated by the numerous alternations of clays, sands, and fine conglomerates.

Goldman[1] has presented petrographic evidence that the Catahoula sandstone of Texas contains a large percentage of well-rounded wind-blown sand. This may be a confirmation of the view that the deposits were laid down near the strand line, where they were moved about by the waves and in many places blown about on sand plains or perhaps in a few places built into dunes and ridges. The presence of leaves and fragments of wood of species such as grow in moist tropical climates, however, indicates that there was an abundance of moisture near the coast and probably a luxuriant tropical vegetation. Such conditions do not harmonize with the assumption of extensive wind erosion along the strand line, and it is therefore reasonable to suppose that the rounding of the sand grains was mostly accomplished before the sands were brought to their present position, though a small amount of wear may have resulted from wind erosion along the coast.

The presence of a large amount of unweathered feldspar suggests that the sands had not been subjected to long-continued weathering in a moist climate.

The great thickness of the sandstones in the territory adjacent to Red River indicates changes toward the headwaters of that stream, probably affecting all the streams in the region of the Great Plains. The most probable explanation is that the streams flowing across the Great Plains were rejuvenated by a regional uplift. This would account for the great influx of sand into the Tertiary sea, and it might be accompanied by an arid climate for some distance east of the Continental Divide, provided the uplift raised the mountains high enough to cut off a portion of the moisture. This would furnish favorable conditions for wind action and for the accumulation of the unweathered feldspar which is so abundant in the sand. Conclusions of this character must for the present be regarded as tentative, because the petrographic studies have been confined to samples of sandstone from Texas, and these have not been compared with samples from other localities. The conditions of deposition may have been somewhat different farther east, where the sediments were derived either wholly or in part from more humid regions, and the conditions may have changed while the sands were being laid down.

STRATIGRAPHY.

DIFFICULTIES OF STRATIGRAPHIC WORK.

Most of the exposures of the Catahoula sandstone are of slight value for stratigraphic study because they have been reduced by the processes of weathering to yellow or orange-colored sands and clays that resemble those found nearly everywhere on the Coastal Plain. This similarity in lithologic character is explained by the fact that the materials in most of the formations were derived from the same sources and on weathering assume the same general appearance. Many of the formations showing this characteristic were deposited under conditions sufficiently diverse to make them distinct in lithologic appearance, so that they can be differentiated where they are unaltered.

[1] Goldman, M. I., Petrographic evidence on the origin of the Catahoula sandstone of Texas: Am. Jour. Sci., 4th ser., vol. 39, pp. 261-287, March, 1915.

Stratigraphic work is further confused by the relations of the different beds resulting from the conditions of sedimentation. Thus the contact between the sands and the clays is nearly everywhere irregular, giving the appearance of unconformity, but the irregularities are due chiefly to the fact that the materials were deposited by shifting currents of varying velocity. During periods of uninterrupted deposition by slow currents the sediments were mostly clay mixed with more or less organic matter derived in part from floating vegetation and in part from plants that grew in swamps and marshes. In some places chemical deposits were made in lagoons, but the major part of the material is detrital. With the incursion of flood waters conditions were altered, and the relatively even surface of the clays laid down by the quiet waters was eroded. The stronger currents left deposits of coarser material, such as sand and more rarely pebbles, and these coarse sediments were subsequently, when the floods subsided, buried beneath clay. Frequent changes in the conditions of deposition produced many alterations in the character of the sediments, with irregular lines of contact and marked discordance of stratification between the deposits of different kinds. In many places fragments of clay loosened from earlier deposits were more or less rounded and then incorporated with coarser materials, forming clay conglomerates or breccias. The final result of the varying conditions of sedimentation was a formation containing innumerable instances of lack of conformability between successive beds. The evidences of unconformity may be seen in many sections and at almost any stratigraphic horizon from the top to the bottom of the formation, being distributed throughout the area of outcrop. As the formation is known from well records and samples of material obtained in drilling to be several hundred feet thick, it is clear that the unconformities are of local character and have no broad stratigraphic significance. Failure to understand the meaning of the irregular contacts of materials in the Catahoula formation, together with an attempt to correlate outcrops solely on the basis of general lithologic character, has led to the inclusion of weathered portions of the Catahoula in what has been called the Lafayette formation. It should not be inferred, however, that the so-called Lafayette formation does not contain other beds besides those mentioned.

STRATIGRAPHIC RELATIONS.

UNDERLYING FORMATIONS.

VICKSBURG LIMESTONE.

Hilgard,[1] who was the first geologist to map the extensive "Grand Gulf" deposits, considered the beds to be essentially horizontal, though he reported high local dips in different directions. From the supposed discordance in dip between the Vicksburg limestone and the "Grand Gulf" sandstone he concluded that the two formations are not conformable.

The dip of the Catahoula sandstone is discussed in detail on pages 217–219, where it is shown that in addition to a general seaward slope the formation has well-defined southerly dips converging toward Mississippi River, thus showing an inclination toward the center of the Mississippi embayment, which must have been at that time the site of rapid sedimentation.

The views of Smith and Aldrich [2] have been fully set forth in outlining their controversy with Dall. The differences between these authors are due to dissimilar methods of work. In correlating exposures Smith and Aldrich relied largely on lithologic characteristics, and the similarity of materials led them to believe that a single formation extended across the edges of formations ranging in age from Eocene to Miocene or Pliocene. Dall, relying on the field observations of Johnson and others, together with the knowledge obtained from a study of the faunas of the Gulf Coastal Plain, reached conclusions similar to those held by Johnson, who, as early as 1893, had succeeded in differentiating four "phases" in what had formerly been called "Grand Gulf."

In southern Mississippi the Catahoula sandstone rests conformably on the Vicksburg limestone; in Alabama it rests conformably on the St. Stephens limestone, the upper part of which is of Vicksburg age. Sections that show a constant relation between the Vicksburg and the Catahoula sandstone have been noted at many places. A typical example is furnished by the

[1] Hilgard, E. W., The later Tertiary of the Gulf of Mexico: Am. Jour. Sci., 3d ser., vol. 22, p. 58, 1881.

[2] Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 16, pp. 835–837, Nov. 21, 1902.

exposures at Vicksburg, Miss., where the following section was measured:

Section at Vicksburg, Miss.

	Feet.
Catahoula sandstone (nonmarine):	
Coarse friable gray sandstone with local lenses of quartzite and some interbedded gray clay.	20
Blue clay, weathering drab, interbedded and interlaminated with gray sand and friable sandstone (exposed at intervals)	35
Vicksburg limestone (marine):	
Chocolate-colored calcareous clay	18
Fine gray to drab sand	6.
Fine sandy marl, very fossiliferous	40

East of Vicksburg many generalized sections were obtained, but details are not available at many places because of poor exposures. The marl bed that forms the basal member of the foregoing section is exposed on Pearl River south of Byram, where it is overlain by dark-colored calcareous clays and these in turn are overlain by interbedded clays and sandstones of the Catahoula formation. Similar conditions were observed on Leaf River near Blakney, Miss., where the same marl bed is overlain by about 40 feet of clay, massive and calcareous near the base and interbedded with gray sandstones in the upper portion of the exposures. On Chickasawhay River near the wagon bridge, 3 miles southwest of Waynesboro, the marl bed is overlain by calcareous clays and marls, with a bed of oyster shells. The contact is not well shown, but small exposures near Triggs Ferry, about 1½ miles west of Waynesboro, show that the drab clays and sands of the Catahoula sandstone rest on an even surface of the clays of the Vicksburg limestone. Farther east, in Alabama, the relation of the Catahoula sandstone to the Vicksburg deposits is the same as in Mississippi, a bed of calcareous clays lying between the upper fossiliferous beds of the Vicksburg and the interbedded sands and clays of the Catahoula. These relations are exhibited south of Manistee, near Manistee Junction, and at several other places.

West of Mississippi River, in Louisiana, the Catahoula sandstone rests unconformably on the Vicksburg limestone, according to Harris and Veatch,[1] who cite Hilgard as authority for the statement. In a subsequent report [2] Harris gives in more detail his views as to the relations of the Catahoula to subjacent formations and makes a definite statement of the direction and the amount of dip. It is clear that he does not agree with Hilgard's statement that the formation is essentially horizontal.

The following section shows the relation between the Catahoula sandstone and the Vicksburg limestone in Catahoula Parish, the type locality of the Catahoula sandstone.

Section in wagon road near Rosefield, Catahoula Parish, La., in sec. 28, T. 11 N., R. 5 E.

	Feet.
Yellow sand	15
Yellow marl containing *Orbitoides mantelli* and *Pecten poulsoni* in calcareous concretions	2
Yellow sand	10
Yellow clay	18
Yellow sand and friable gray micaceous sand rock which weathers to yellow incoherent sand	25
Red clay	6

No. 1 of this section is a typical weathering product of the Catahoula sandstone, and from the presence of Vicksburg fossils in No. 2 it, together with the underlying material, would be placed in the Vicksburg. However, Nos. 3 to 6 are lithologically similar to the Catahoula sandstone, and it is apparent that the two formations are interbedded at this locality. Farther west the Vicksburg is entirely replaced by the Catahoula sandstone. In addition to being interbedded with the Vicksburg the Catahoula sandstone contains beds of calcareous clay at many localities. The presence of such a clay bed is shown in the following section:

Section of Catahoula sandstone at Harrisonburg, La.

	Feet.
Gray sand	2
Yellow and orange-colored sand containing a few scattered pebbles arranged in thin layers	8
Yellow sand and gravel	3
Yellow sand grading downward into gray sandstone with a thin laminæ of clay	2
Gravel	2
Interbedded gray clay and sandstone, some layers showing cross-bedding	8
Dark-gray clay with greenish tinge where fresh	10
Interbedded gray sandstone and clay	2
Dark-gray clay	4
Yellow sand	4
Gray sandstone	5
Massive green clay	5
Massive green sandstone containing pebbles; surface weathered to light yellow	4
Green clay	2
Massive gray sandstone	4
Massive green clay	15

[1] Harris, G. D., and Veatch, A. C., Geology of Louisiana, pt. 5, p. 95, 1899.

[2] Harris, G. D., Geology of the Mississippi embayment: Geology of Louisiana, pt. 6, p. 28, 1902.

The lowest bed of clay is distinctly calcareous where fresh, the surface of the layers and cracks in the beds being covered with numerous rosettes of calcium carbonate. The sandstone overlying it is also calcareous, though the percentage of calcium carbonate is smaller than in the clay.

FAYETTE SANDSTONE.

Veatch[1] included in his Catahoula formation in central and western Louisiana beds that pass laterally into typical clays and thin-bedded sands and sandstone of the Jackson formation. This portion of the formation is in the present report correlated with the Fayette sandstone of Texas. Harris[2] described the relations of these sandstones to the Jackson formation in western Louisiana as unconformable and regarded the poorly preserved remnants of marine fossils in the sandstone as survivors from the Jackson epoch. Recent study in western Louisiana shows that the irregular contact described by Harris is like those occurring at most places where coarse sandstones have been deposited on clays, the irregularities in the surface of the clay being such as are commonly produced by currents bearing coarse detritus.

The Fayette sandstone of western Louisiana has a thickness of 100 to 200 feet. It is more quartzitic than the Catahoula sandstone (see Pl. LIV) and is locally interbedded with clays that are darker and more calcareous than the clays of the Catahoula. The two formations differ in origin. Both contain silicified wood and imprints of fossil leaves, and in addition the Fayette sandstone contains many imprints of marine fossils. The Catahoula sandstone is apparently nonmarine, being devoid of traces of marine fossils except where it merges with the Vicksburg limestone.

The facts outlined above lead to the conclusion that the Catahoula sandstone of Mississippi and Alabama is conformable with the underlying Vicksburg limestone (represented in Alabama in the upper part of the St. Stephens limestone), because if the Vicksburg had been eroded before the deposition of the Catahoula the uppermost layers of the Vicksburg would be missing in some of the sections. In eastern Louisiana the Catahoula sandstone dovetails with the Vicksburg, and in western Louisiana it is conformable with the Fayette sandstone. These facts indicate that the deposition of the Catahoula followed that of the underlying marine formations without a stratigraphic break and that it began in Texas and western Louisiana and was gradually extended eastward to Mississippi. In Mississippi and Alabama its deposition began at the end of the Vicksburg epoch and extended across the entire area where the Catahoula is exposed. However, brackish-water conditions persisted in places for a short time after the deposition of the upper marl bed of the Vicksburg, as shown by the oyster bed near Waynesboro, Miss.

OVERLYING FORMATIONS.

HATTIESBURG CLAY.

The Catahoula sandstone is overlain conformably by the Hattiesburg clay, of Oligocene age. This formation ranges in thickness from 300 to 350 feet in Alabama and Louisiana and to a maximum of 450 feet in central and western Mississippi. It consists of massive blue and gray clays with subordinate amounts of sands and sandstones. Locally the clay beds are consolidated into hard ledges, though this rock is not restricted to any one formation, being found in all the Oligocene and Miocene deposits of the Gulf embayment. In some places the clays contain fragments of lignitized wood and imprints of fossil plants. A deposit of this character a few miles east of Hattiesburg, Miss., near McCallum, furnished some identifiable remains of fossil plants. At Hattiesburg, the type locality, the clays are exposed in the banks of Bowie Creek and Leaf River and in the lower portions of the hills that border these streams.

The name Hattiesburg was first used by Johnson, whose definition is given on page 211. The type locality of the Hattiesburg clay is the same as the type locality of Johnson's Hattiesburg phase or formation,[3] but a brief statement of the significance of the new term Hattiesburg clay is given here because it is used to include the portion of Johnson's Fort Adams or Ellisville phase that extends from

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 42–43, 1906.

[2] Harris, G. D., Geology of the Mississippi embayment: Geology of Louisiana, pt. 6, p. 28, 1902.

[3] Johnson, L. C., The Miocene group of Alabama: Science, vol. 21, pp. 90–91, 1893.

the mouth of Okatoma Creek eastward past the falls on Leaf River near Eastabutchie to Chickasawhay River between Winchester and Waynesboro.

The Hattiesburg clay is readily recognizable from central Alabama, where it merges into the more sandy fossiliferous beds of the Alum Bluff formation, westward to eastern Texas. In western Louisiana and eastern Texas it is the lower portion of what Veatch[1] mapped as Fleming clay. The relation of the overlying Miocene to the Hattiesburg clay is unconformable, and this permits the separation of what has been called the Fleming clay in Louisiana and along the eastern border of Texas into two parts. The lower part, which, from its stratigraphic relations is included in the Hattiesburg clay, is more sandy and much less calcareous than the overlying Miocene clays.

PASCAGOULA CLAY.

A series of blue, green, and gray clays, locally calcareous, with interbedded sands and more rarely sandstones, lying unconformably above the Hattiesburg clay, has been called the Pascagoula clay. This formation is locally fossiliferous and has furnished remains of marine or brackish-water invertebrates at Shell Bluff and Givhens Landing, on Chickasawhay River, Miss., and in numerous wells in the southern part of the State. A somewhat different fauna has been obtained from the formation at Pine Prairie and southwest of Alexandria, La., and at Burkeville, Tex. The formation ranges in thickness from about 250 feet in Alabama to 450 feet near Mississippi River in Louisiana and along the Gulf coast in Mississippi. In western Louisiana and eastern Texas the thickness has not been accurately determined but it is thought to be about 250 or 300 feet. Local variations in thickness are to be expected, because the Pascagoula clay is overlain unconformably by sands and clays of Pliocene age and rests unconformably on the Hattiesburg clay.

The Pascagoula clay differs from Johnson's Pascagoula phase or formation[2] by including the portion of his Fort Adams or Ellisville phase extending from Tunica, La., to Columbia, Miss. The type locality is, however, the same, and the difference is largely due to a more thorough understanding of the distribution of the formation. West of Mississippi River the Pascagoula clay extends across southern Louisiana and eastern Texas and includes the upper portion of what Veatch[3] called the Fleming clay.

CITRONELLE FORMATION.

The Pascagoula and Hattiesburg clays and the Catahoula sandstone are in places overlain by sands, gravels, and clays that from their fossil flora (identified by E. W. Berry) are known to be of Pliocene age. These deposits, which heretofore have been called Lafayette formation, Orange sand, etc., have recently been named the Citronelle formation,[4] from the town of Citronelle, in northern Mobile County, Ala. The formation consists of yellow and red clays and sands, with lenses and layers of gravel in which the pebbles range from a fraction of an inch to several inches in diameter. Subangular chert is the most abundant constituent of the gravel, though it contains everywhere a varying percentage of rounded quartz pebbles.

The Citronelle formation, which is largely nonmarine, varies greatly in thickness, ranging from a minimum of 30 feet where it overlies the Catahoula to over 150 feet where it rests on the outcropping edge of the Pascagoula and to a maximum of 400 feet nearer the coast, where it underlies the Pleistocene deposits. The relation of the Citronelle to both the overlying and underlying formations is unconformable, a fact which accounts for some of the variations in thickness. Other variations are explained by the character of the surface of the formation, which is composed of a series of plains diminishing in elevation toward the coast and toward the axes of the principal valleys that cross the formation.

CORRELATIONS.

The Oligocene series of western Florida includes in descending order the Alum Bluff formation, the Chattahoochee formation, and the Marianna limestone. The Marianna is of Vicksburg age. The marine Chattahoochee formation passes westward in Alabama by gradation through fossiliferous marls into

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 43–44, 1906.

[2] Johnson, L. C., The Miocene group of Alabama: Science, vol. 21, pp. 90–91, 1893.

[3] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 43–44, 1906.

[4] Matson, G. C., U. S. Geol. Survey Prof. Paper 98, pp. 167–192, 1916 (Prof. Paper 98–L).

the nonmarine sandstones and clays of the Catahoula sandstone. The equivalence of the Chattahoochee formation and that portion of the Catahoula sandstone lying east of Mississippi River is further shown by the relations of these formations to those above and below them. The Chattahoochee formation of Florida conformably overlies the Marianna limestone, the Florida representative of the Vicksburg limestone,[1] and the Catahoula sandstone of Alabama and Mississippi rests conformably on the Vicksburg limestone.

The Chattahoochee formation is overlain conformably by the Alum Bluff formation, and the Catahoula sandstone is overlain conformably by the Hattiesburg clay. The equivalence of the Alum Bluff formation and the Hattiesburg clay has been established by tracing their physical continuity and by fossil plants identified by E. W. Berry.[2]

The correlation of the Catahoula sandstone west of Mississippi River has already been explained, but it may be summarized by stating that in this area the Catahoula includes sandstones and clays equivalent not only to the Chattahoochee formation, but also to the Vicksburg limestone, rests conformably on the Jackson formation and the Fayette sandstone, and is conformably overlain by the Hattiesburg clay.

The table opposite page IV shows the correlation of the Tertiary formations in the Gulf States.

CONCLUSIONS.

The Catahoula sandstone consists of alternating sandstones and sands, with lenticular beds of clay, the arenaceous sediments predominating. Conglomerates are rare, though small quartz and chert pebbles occur in some of the layers of sand, and pebbles of clay are found at many localities and at different stratigraphic horizons. The formation is nonmarine but was deposited near the strand line, where small bodies of brackish water were isolated and, on evaporation, formed precipitates of salt and gypsum. The streams that transported the materials now constituting the formation had varying velocities and made deposits ranging in texture from clay to fine-grained conglomerates. The floods that transported the coarse materials eroded the surfaces of existing clay deposits, thus forming irregular contacts and incorporating more or less rounded fragments of the clay in the sands. The fossils, which are rare, are mostly leaves, but molluscan remains occur at a few places. One of these localities is at Chalk Hills, near Rosefield, La., where shells of unios (?) are found in a sandstone, and another is in a cut on the Texas & Pacific Railway, 1 mile east of Lena, where fragments of oyster shells occur in a lens of limestone.

Weathering of the formation produces red, yellow, and mottled sands and clays that have commonly been classed as Orange sand and placed in a separate formation called the Lafayette. This classification has resulted from the existence of numerous local unconformities and the general resemblance of these weathered sands and clays to similar materials occurring in other portions of the Coastal Plain.

The sections in the vicinity of Harrisonburg and Rosefield, La., show that the sandstones and clays of the Catahoula are interbedded with the lower Oligocene limestones and marls (Vicksburg limestone). Farther west in Louisiana they replace all the marine lower Oligocene beds. Similar sandstones (Fayette sandstone) containing marine fossils are the equivalents of some of the calcareous and fossiliferous beds of the Jackson formation in western Louisiana and represent nearly all of the Jackson in central Texas. These facts account in part for the increased thickness of the formation in central Louisiana, amounting to several hundred feet, and explain the form of the outcrop of the formation in the Mississippi embayment and the Red River valley.

The belief that the Catahoula sandstone is essentially horizontal, which, if correct, would be a fatal objection to the merging of the Catahoula and older formations, is shown to be an error. Information that was not available at the time of the early examinations shows clearly that the dips of the Catahoula range from slightly more than 21 feet to the mile in east-central Mississippi to about 38 feet in central Louisiana and are probably even greater than 50 feet near the Louisiana-Texas boundary.

[1] Cooke, C. W., unpublished notes.
[2] Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 744, 1912.

THE FLORA OF THE CATAHOULA SANDSTONE.

By Edward Wilber Berry.

INTRODUCTION.

During the progress of my studies of the fossil floras of the Gulf Coastal Plain, embracing all horizons from the Lower Cretaceous to the Pleistocene and prosecuted under the general direction of T. Wayland Vaughan, material representing the floras of all the major stratigraphic units in the area extending from western Florida to central Texas has been discovered. Field work and office studies of all these floras have proceeded more or less simultaneously, and a large amount of manuscript in various stages of completion has been accumulated. The floras of the Upper Cretaceous and Eocene of South Carolina and Georgia have been described [1] and a report on the very large lower Eocene floras is now in press.[2]

Because of their exceptional stratigraphic importance in solving some of the problems connected with the so-called "Grand Gulf complex" I was asked to submit a report on the fossil plants discovered within the limits of the Catahoula sandstone. This report was submitted in March, 1913. Since it was written a number of additional collections have been made from scattered localities, notably in eastern Texas, where through the cooperation of Mr. C. L. Baker, working under the supervision of Mr. E. T. Dumble, several important collections were obtained. It is my plan to discuss these several Coastal Plain floras exhaustively, as in the reports cited above, and for this reason it has been deemed inadvisable to endeavor to bring the description of the Catahoula flora entirely up to date at this time. In the following pages only the more important discoveries that have been made since March, 1913, have been included. The plants from the Catahoula sandstone that still await description and illustration are largely represented by petrified wood, and until these remains are studied it will be impossible to determine whether any of the fossil plants obtained in western Louisiana and eastern Texas are of late Eocene (Jackson) age, although this seems to be very probable.

The uppermost Eocene, Oligocene, and lowest Miocene deposits of Europe have furnished very extensive fossil floras, several of which, such as those of the gypsiferous shales of Aix and other localities in southeastern France,[3] of the lignites of Haering, in Tyrol,[4] of Monte Promina, in Dalmatia,[5] and of the Styrian lignites,[6] are classic.

In striking contrast to the abundant floras in Europe, very few plants of these ages have been found in North America, and practically nothing is known of the Oligocene floras of this continent. For this reason, as well as for the light it has shed on certain stratigraphic problems, the small flora in the Oligocene of the embayment area, from Texas eastward to western Mississippi, is of unusual interest, although it is in general poorly preserved and fragmentary.

The collection on which the present paper is based comes from ten localities. Six of these localities—5 miles north of Jasper in Jasper County, Tex.; in Rapides and Grant parishes, La.; Washington, Adams County, Miss.; 5 miles north of Waynesboro, Wayne County,

[1] Berry, E. W., The Upper Cretaceous and Eocene floras of South Carolina and Georgia: U. S. Geol. Survey Prof. Paper 84, 1914.

[2] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91 (in press).

[3] Saporta, Gaston de, Études sur la végétation du sud-est de la France à l'époque tertiaire: Annales sci. nat., Botanique, 1862 to 1889.

[4] Ettingshausen, Constantin, Die tertiäre Flora von Häring in Tirol; K. k. geol. Reichsanstalt Wien Abh., Bd. 2, Abt. 3, 118 pp., 31 pls., 1853.

[5] Mainly elaborated by Ettingshausen, K. Akad. Wiss. Wien Denkschr., vol. 8, 1855.

[6] Set forth in a large number of papers by Ettingshausen and Unger.

Miss.; and on Bayou Pierre, Miss., near the Claiborne-Copiah county line—have furnished only the petrified remains of the wood of the very abundant tropical palms which clothed the shores of the Oligocene sea. The remains of identifiable leaves have been found at only four localities. Two small collections were made at the so-called Chalk Hills, 2 miles south of Rosefield, La., one by G. D. Harris [1] and the other by me; a small collection was made by me near King, 5 miles south of Florence, Rankin County, Miss.; and a fourth collection came from Trinity County, Tex.

The species listed on page 230, 24 in number, have been identified from these 10 localities. These species include one fungus, two ferns, eight palms, a fig, an indubitable member of the family Proteaceæ (Embothrites), a species of pond apple or Anona, a species of rain tree (Pithecolobium), of the family Mimosaceæ; abundant remains of four varieties of satinwood (Fagara), of the family Rutaceæ; a species of Judas thorn (Paliurus), of the family Rhamnaceæ; another of coast myrtle or Myrcia, of the family Myrtaceæ; and two species of the family Sapotaceæ related to the genus Bumelia or iron wood. The collections include also fragmentary remains of other species that are too poor for satisfactory identification.

The most abundant and widely distributed elements in this Oligocene flora are the petrified remains of palm wood which are referred to the genus Palmoxylon and many of which are in an excellent state of preservation. Seven species are based on remains of this sort, and all seven of these species have been previously described by Felix, Stenzel, or Knowlton. A short paper by Knowlton [2] on two species of palm wood from Rapides Parish, La., is the only previous contribution to the paleobotany of the Oligocene of this general region. All the other species are new to science.

Although this flora is too small to be representative, and the majority of the forms described have been found only in this region, nevertheless it furnishes decisive information on the physical conditions along the border of the Oligocene sea and also abundant data for determining the approximate age of the deposits. As the climatic conditions which may legitimately be deduced from this assemblage form one of the factors used in correlation, this phase of the problem may be considered first.

My studies during the last few years have resulted in the discovery of extensive Tertiary floras throughout southeastern North America, and although the descriptions of these floras have not yet been published, they have been rather fully worked out in manuscript. An enumeration at the present time shows a flora of 10 species in the Midway (?), 335 species in the Wilcox, about 75 species in the Claiborne, about 75 species in the Jackson (all Eocene), and 15 species in the Apalachicola (Oligocene). Fairly definite evidence regarding the climatic conditions of the border land is furnished by these floras, and this evidence is capable of being checked by the abundant marine faunas, so that what is said in the following paragraphs on the climate of Oligocene time is based not only on extensive comparisons between the Oligocene and the existing floras, but also on a knowledge of the floras of the epochs that immediately preceded and followed the Oligocene.

To turn now to the different units in this flora it may be noted that the fern genus Acrostichum is exclusively tropical in the existing flora, its most abundant species being the widespread *Acrostichum aureum*, a very gregarious inhabitant of coastal swamps, where it associates with mangroves and nipa palms. The existing species of the fern genus Lygodium, with but one exception, are inhabitants of coastal tropical thickets. The very great abundance and diversity of palms in the Oligocene flora also indicates tropical conditions, for although the study of palm woods has not reached a point where generic relationships can be positively affirmed, Stenzel, our foremost authority on palm anatomy, considers all these Oligocene species as most closely related to either Corypha or Cocos, and in addition several are present among the silicified woods of the island of Antigua, where tropical conditions must have prevailed throughout the Oligocene epoch. Ficus is not exclusively a tropical type, but of the 600 existing species a great majority are confined to the equatorial region and only a very few penetrate into the warmer parts of the Temperate Zone. The genus Embothrites

[1] I am indebted to Mr. Arthur Hollick and the authorities of the New York Botanical Garden for the privilege of studying this collection.

[2] Knowlton, F. H., Description of two species of Palmoxylon—one new—from Louisiana: U. S. Nat. Mus. Proc., vol. 11, pp. 89-91, pl. 30, 1888.

is named from its resemblance to the existing genus Embothrium Förster and may or may not be strictly comparable with that genus. Embothrium has several species in the mountains of tropical Australia and in the Andean region of South America, from Peru southward into the Temperate Zone. It seems probable that the Tertiary genus is really a distinct member of the family Proteaceæ, which in the existing flora is largely tropical in its distribution. The genus Anona has about 50 existing species and occurs in all tropical countries. The greatest distance from the Equator that it reaches is shown by the species found on the Florida keys. The genus Pithecolobium of the family Mimosaceæ, has over 100 existing species, all of which are confined to the Torrid Zone.

The genus Fagara, which is so abundant at the Chalk Hills locality in Louisiana, has over 150 existing species, which are cosmopolitan in tropical and subtropical countries. The ecologic conditions at the locality where the Fagara leaves are so abundant are closely comparable with those prevailing at the present time in the lagoons behind the keys of southern peninsular Florida, where very similar species of Fagara are among the commonest of coastal plants. The sediments are, however, very different. At the Chalk Hills there are alternate layers of coarse sands and finely divided chert, but behind the Florida keys the deposits are calcium carbonate. The genus Paliurus, of which a small-leafed species is represented in the present collection, is almost entirely extinct at the present time, over 90 per cent of its known species being of Tertiary age. The two existing species are of warm temperate Eurasiatic habitats, but this fact lacks significance in the present connection, for the fossil forms are almost invariably associated with floras which must be regarded as at least subtropical. The genus Myrcia, represented by a single species in this Oligocene flora, includes over 400 existing species confined exclusively to the American Tropics and embracing many closely comparable coastal forms. The genus Bumelia, to which the two forms of Oligocene Sapotaceæ are related, is confined to America in the existing flora, embracing about a score of species distributed from northern Brazil through Central America and the West Indies to the southern United States. Among these the form most similar to the fossil species is *Bumelia horrida* Grisebach, of the West Indies.

It will be seen from the foregoing enumeration that this fossil flora is strictly tropical in its facies—in fact, it must be regarded as the most tropical flora known from the Tertiary formations of the Southern States. This conclusion is borne out by a study of the associated marine faunas, which are regarded by Vaughan[1] as indicating a bottom temperature between 70° and 80° F.

The flora contains no upland or inland types and may be regarded as a strictly coastal flora made up of groups comparable with those found along the strand in the present-day Tropics.

As bearing on the age of the deposits in which the flora here discussed has been found, it may be noted that this flora is of too tropical a character, even after allowances are made for my perhaps undue emphasis on its tropical aspect, to have been capable of existing during any post-Chipola epoch in our Southern States. This fact alone effectually disposes of the possibilities that the part of the so-called "Grand Gulf formation" immediately overlying the Vicksburg is of Pliocene or more recent age, as has been asserted by some students. Moreover, these deposits are interbedded with the Vicksburg limestone in Louisiana and immediately overlie it in central Mississippi, much of the petrified palm wood being found in depressions in the Vicksburg surface. At least one and probably two of the species of palm wood are common to the Oligocene of the island of Antigua. Another occurs in the Jackson of Louisiana, and a fourth in the Vicksburg of Alabama. Similarly the palm leaves referred to *Sabalites vicksburgensis* occur in the Jackson of Texas.

Finally the facies of the flora as a whole is that of the abundant floras found in the early Oligocene of southern Europe, notably in Provence, France, in Tyrol, and in Dalmatia and Styria. Not only does it exhibit this parallelism with these European early Oligocene floras, but when the genera are considered separately it appears that almost without exception they have not been found in what are now temperate latitudes in any beds younger than Oligocene.

[1] Vaughan, T. W., A contribution to the geologic history of the Floridian Plateau: Carnegie Inst. Washington Pub. 133, p. 152, 1910.

An exhaustive statement regarding the stratigraphic relations to one another of the several outcrops of the Catahoula at which fossil plants have been discovered is postponed until the final report has been completed. Appended is a list of the species described in the following pages, with their stratigraphic position as determined by Mr. Matson.

Fossil plants from the Catahoula sandstone.

Name.	Locality.	Horizon.
Pestalozzites minor	Chalk Hills, La	Catahoula sandstone (in beds of Vicksburg age).
Lygodium mississippiensis	King, Miss	Catahoula sandstone (in beds of Chattahoochee age).
Acrostichum smithi	do	Do.
Cupressites sudworthi	Chalk Hills, La	Catahoula sandstone (in beds of Vicksburg age).
Sabalites vicksburgensis	do	Do.
Palmoxylon microxylon	Rapides Parish, La	Catahoula sandstone (age ?).
Palmoxylon cellulosum	Rapides Parish, La.; Bayou Pierre, Miss.	Catahoula sandstone (in beds of Chattahoochee age).
Palmoxylon texense	5 miles north of Jasper, Tex	Catahoula sandstone (in beds of Vicksburg age).
Palmoxylon lacunosum	Fish Creek, north of Pollock, La.	Do.
	1 mile east of Galbraith, La	Do.
Palmoxylon remotum	5 miles north of Waynesboro, Miss.	Surface of Vicksburg.
Palmoxylon mississippiensis	Washington, Miss	Catahoula sandstone (age ?).
Palmoxylon ovatum	do	Do.
Ficus sp. (fruits)	Chalk Hills, La	Catahoula sandstone (in beds of Vicksburg age).
Embothrites ungeri	do	Do.
Anona texana	Trinity County, Tex	Fayette sandstone (in beds of Jackson age).
Pithecolobium oligocænum	Chalk Hills, La	Catahoula sandstone (in beds of Vicksburg age).
Fagara catahoulensis orbiculata	do	Do.
Fagara catahoulensis coriacea	do	Do.
Fagara catahoulensis major	do	Do.
Fagara catahoulensis elongata	do	Do.
Paliurus catahoulensis	do	Do.
Myrcia catahoulensis	do	Do.
Bumelia vicksburgensis	do	Do.
Carpolithus bumeliaformis	do	Do.

THE FLORA.

Phylum THALLOPHYTA.

Fungi imperfecti.

Order MELANCONIALES.

Family MELANCONIACEÆ.

Genus PESTALOZZITES Berry, n. gen.

The genus Pestalozzites is proposed for fossil leaf-spot fungi that attacked fan palms and formed nondiffuse spots with plainly marked outlines and more or less regular form. It was suggested by the identity in appearance between *Pestalozzites sabalana* Berry (manuscript name) and Pestalozzia sp. cf. *P. palmarum* Cooke[1] found infesting *Serenoa serrulata* (Michaux) Hooker. I fully realize that appearances are deceptive and that there are a large number of parasitic fungi which attack existing palms, as, for example, species of the genera Ascochyta, Diplodia, Exosporium, Phoma, Pleospora, and Stagonospora, any of which might cause leaf spotting. The name given may well serve, however, as a form genus for remains of this sort and no harm is done in commemorating the resemblance to the existing genus Pestalozzia De Notley, the only modern genus whose effects are so regular in appearance.

In a considerable amount of fossil material the characteristic spotting of this type is mainly confined to the leaf rays of a Sabal-like form, but in the Claiborne species *Thrinax eocenica* Berry it occurs on both the rays and the rachis.

Pestalozzites minor Berry, n. sp.

Plate LV, figure 2.

Essential characters unknown. Found infesting the rays of *Sabalites vicksburgensis* Berry, where it forms relatively small, usually nearly circular leaf spots, which average about 1 millimeter in diameter. These remains are of trifling value from either the botanist's

[1] Kindly identified for the writer by Mrs. Flora W. Patterson, of the Bureau of Plant Industry, U. S. Department of Agriculture.

or the geologist's point of view, nevertheless they are of considerable interest as indicating the presence of this type of plant life in the Oligocene epoch. Indistinguishable remains are present on both the rays and the rachis of the Claiborne species *Thrinax eocenica* Berry.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collection: New York Botanical Garden.

Phylum PTERIDOPHYTA.

Order FILICALES.

Family SCHIZÆACEÆ.

Genus LYGODIUM Swartz.

Lygodium mississippiensis Berry, n. sp.

Plate LV, figures 3, 4.

Pinnules small and somewhat coriaceous, bilobate. Base rounded. Margins entire, slightly undulate. Lobes narrow, linear, with rounded tips, diverging at an angle of about 90° and separated by a right-angled sinus that approaches within 6 or 7 millimeters of the base. Width of lobes about 7 millimeters; length about 3 centimeters. Venation characteristic of the genus; rather open, considering the small size of the pinnules. At or just above the base the leaf trace of the pinnule forks at an angle of 55° to 66°, the branches curving outward and pursuing a course approximately in the middle of the lobes until they become obsolete by repeated branching. The branches go off at acute angles and curve outward, forking one or more times (usually but once) by a narrow dichotomy and ending in the margin.

The present species is based on very scanty and fragmentary remains found also in the Fayette sandstone of Trinity County, Tex. It is fully recognized that Lygodium pinnules are in general variable in size, outline, and lobation and that the foregoing description is inadequate in many respects. At the same time this species represents a characteristic element in a meager flora which is of great interest to the student of comparative paleobotany. It is clearly distinct from the Wilcox or Claiborne species of Lygodium, the tendency seemingly having been in the direction of a progressive diminution in the size of the pinnules, a feature also noted in the records of the species of Lygodium found in the Tertiary of Europe.

It resembles somewhat but is perfectly distinct from *Lygodium dentoni* Lesquereux,[1] of the Green River formation in the Rocky Mountain region. It also resembles what J. Starkie Gardner terms a "dwarfed barren frond of *Lygodium kaulfussi* Heer from the Lutetian of southern England."[2] Saporta has described three species from the Sannoisian of southern France, a horizon not very different from the present one, which greatly resembles this species. They are *Lygodium parvifolium*,[3] *L. exquisitum*,[4] and *L. distractum*.[5] *Lygodium parvifolium* is a small bilobate form very close to the present species; in fact, the two may be identical, but in the present state of our information, both species being rare and scantily represented, it is wiser to keep them distinct.

Occurrence: Catahoula sandstone near King, 5 miles south of Florence, Rankin County, Miss.

Collection: United States National Museum.

Family POLYPODIACEÆ.

Genus ACROSTICHUM Linné.

Acrostichum smithi Berry, n. sp.

Plate LV, figures 5–8.

Frond habit undeterminable, presumably pinnate and of large size. Pinnæ variable in size and outline, ranging from reduced elongate-elliptical pinnæ like those of the Claiborne-Jackson species *Acrostichum georgianum* Berry to forms with long, narrow pinnæ and other forms with pinnæ fully as large as those of the Yegua or "Cockfield" (upper Claiborne) and Green River species *Acrostichum hesperium* Newberry. The margins are entire but somewhat irregular and more or less revolute. The leaf substance is thick and the texture coriaceous, much more so than in either of the forms cited. Midrib stout and more or less flexuous. Lateral venation very fine and obscure, of the typical Acrostichum type, more ascending than in the species

[1] Lesquereux, Leo, Contributions to the fossil flora of the Western Territories, pt. 2, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 63, pl. 65, figs. 12, 13, 1878.

[2] Gardner, J. S., and Ettingshausen, Constantin, British Eocene Flora, vol. 1, p. 67, pl. 13, fig. 8, 1882.

[3] Saporta, Gaston de, Études sur la végétation du sud-est de la France à l'époque tertiaire, vol. 3, suppl. 2, p. 87, pl. 1, fig. 14, 1867; Dernières adjonctions à la flore fossil d'Aix-en-Provence, pl. 2, fig. 6, 1889.

[4] Saporta, Gaston de, op. cit. (Études, etc.), p. 88, pl. 1, fig. 13.

[5] Saporta, Gaston de, op. cit. (Dernières adjonctions, etc.), pt. 1, p. 24, pl. 2, fig. 8.

cited, with very narrow and much elongated areolæ.

This species is abundant but fragmentary in the Mississippi Oligocene, where the matrix is an argillaceous sand or sandy mudstone of shallow-water origin and not especially favorable for the preservation of plant remains. Some years ago Dr. Eugene A. Smith showed me a nearly complete pinna about 12 centimeters in length that he had collected from this locality. I have not seen this specimen recently but presume it is still in the collections of the Alabama Geological Survey at University, Ala. The species is named for Dr. Smith, who has done so much for southern geology and who discovered the plant locality near King, Miss., that makes it possible to correlate the deposits definitely.

The genus Acrostichum is made up of tropical marsh ferns, its most representative species being *Acrostichum aureum* Linné, a cosmopolitan and common tropical and subtropical type inhabiting the mangrove and nipa tidal swamps as well as similar situations throughout the old and new worlds. The genus appears in the basal Eocene and has several European and American species in Eocene and Oligocene deposits, the principal forms being *Acrostichum lanzeanum* (Gardner and Ettingshausen),[1] of the European Lutetian and Bartonian, and *Acrostichum georgianum* Berry and *Acrostichum hesperium* Newberry, of the Claiborne, Jackson, and Green River deposits. Several other species from the European Oligocene (Sannoisian, Tongrian, and Chattian) that are comparable with the present form have been described. The present species is especially like *Acrostichum strictum* (Squinabol), of the Lower Tongrian of Ste. Justine, near Savone, in Liguria, Italy.

Occurrence: Catahoula sandstone near King, 5 miles south of Florence, Rankin County, Miss.

Collection: United States National Museum.

[1] Gardner, J. S., and Ettingshausen, Constantin, British Eocene flora, vol. 1, p. 26, pl. 1; pl. 2, figs. 1–4, 1879.

Phylum SPERMATOPHYTA.

Class GYMNOSPERMÆ.

Family PINACEÆ.

Genus CUPRESSITES Bowerbank.

Cupressites sudworthi Berry, n. sp.

Plate LV, figure 1.

Cones small, subglobose, 1.5 to 2 centimeters in diameter. Cone scales ligneous, decussate, less than 10 in number, the exact number not determinable, peltate in form, with a thick axis abruptly dilated to the subangular four or five sided, expanded and transversely flattened tip, which is thick and radiately wrinkled from the subcentral mucronate umbo.

The present species is based on poorly preserved and somewhat crushed cones, whose substance at the Chalk Hills locality is replaced by a friable kaolinitic deposit. No traces of coniferous foliage have been found in association with them. These cones are very similar to those from the Lower Oligocene of Haering, in Tyrol, described by Unger[2] as *Cupressites taxiformis*, which Gardner,[3] apparently on good grounds, transfers to the genus Cupressus and associates with cones from the supposedly older beds at Bournemouth (Middle Bagshot), in the south of England. The present material is too poorly preserved to show whether the proximal scales are fused or free, or whether sterile scales persist at the base of the cone. As identity with *Cupressus taxiformis* can not be positively established these remains are described as new, and as they can not be definitely referred to the genus Cupressus rather than Chamæcyparis, they are referred to the form genus Cupressites of Bowerbank and named in honor of Mr. George B. Sudworth, of the United States Forest Service. The species in a lignified state is present in beds of lower Jackson age in western Tennessee.

[2] Unger, Franz, Chloris protogæa, p. 18, pl. 8, figs. 1–3; pl. 9, figs. 1–4, 1847.

[3] Gardner, J. S., British Eocene flora, vol. 2, p. 26, pl. 9, figs. 22–26, 28–30, 1883. Other figures show the characteristic dimorphic foliage.

The modern species of Cupressus are about 12 in number, of comparatively warm climatic requirements, found in southern Eurasia and in Pacific North America from California southward to Central America, usually frequenting sandy habitats near the coast. The modern species of Chamæcyparis number four or five and are confined to the Atlantic and Pacific coast regions of North America and similar, mostly swampy habitats in Japan and Formosa.

Occurrence: Chalk Hills, 2 miles south of Rosefield, La.

Collection: United States National Museum.

Class ANGIOSPERMÆ.

Subclass MONOCOTYLEDONÆ.

Order ARECALES.

Family ARECACEÆ.

Genus SABALITES Saporta.

Sabalites vicksburgensis Berry, n. sp.

Leaves of variable size, flabellate, the maximum diameter estimated (from collected material) at about 120 centimeters. Rachis relatively slender, unarmed, not enlarged at the base of the leaf, continued upward as a long, slender, gradually narrowed acumen. Whether or not the two surfaces of the leaf differ, as they do in *Sabalites grayanus* Lesquereux, of the Wilcox, and *Sabalites apalachicolensis* Berry, of the Apalachicola group, can not be determined from the available material. Fragmentary counterparts of the base of a leaf indicate that the acumen is practically the same on both leaf surfaces. Rays carinate, about 40 in number; basal ones becoming smaller, narrower, closer, and more curved proximad; all are extended, linear-lanceolate, and acuminate, becoming free distad for greater or less distances, usually from one-third to one-half their total length. Maximum observed width of rays (near the middle), 3.6 centimeters. Midrib of rays stout. Lateral veins parallel with midrib, stout, about 30 on each side, one or two at irregular intervals on each side more prominent than their fellows, connected by fine transverse veinlets at right angles to the main parallel venation. Leaf substance relatively thin but stiff.

The present species is close to previously described forms of Sabalites, the specific relations of all of which are not certainly assured. It differs from *Sabalites apalachicolensis* Berry (unpublished) in its more slender rachis, longer acumen, thinner leaf, and more prominent venation. It may be distinguished from the widespread Wilcox form *Sabalites grayanus* Lesquereux by its more slender rachis, lack of enlargement at the base of the leaf, and thinner texture.

Sabalites vicksburgensis was a form that resembled in its habitat *Sabalites apalachicolensis* as well as the modern *Sabal palmetto* Roemer and Schultes—that is to say, it probably never flourished far from the coast. It is represented in the collections by little first-class material, although the numerous ray fragments in the argillaceous sandstones of the Chalk Hills show that it must have been an abundant element in the flora of Vicksburg time. The Vicksburg is notable for the abundance of petrified fragments of palm stems found in its deposits and distributed in an arc extending from Texas through Louisiana, Mississippi, and Alabama, and probably reaching the West Indies on the one hand and Mexico on the other. Seven different species based on these remains are described in the present study and bear eloquent testimony to the diversity of the palm flora and to the tropical character of the Vicksburg climate. Some of the Chalk Hills rays are infested with a leaf-spot fungus which I have described as *Pestalozzites minor*.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collection: United States National Museum.

Genus PALMOXYLON Schenk.

Palmoxylon. Schenk, Engler's Bot. Jahrb., vol. 3, p. 355, 1882.

The silicified remains of palm wood are exceedingly common in the late Eocene and Oligocene deposits from Texas eastward across Louisiana, Mississippi, and Alabama, and reappear in several of the Greater and Lesser Antilles, as well as in Mexico and on the Isthmus of Panama. These remains are fragmentary for the most part, although several large trunks have been seen. Usually they are found weathered out upon the surface, or reworked and more or less rolled, in Pleistocene and Recent deposits, in or immediately south of the area of outcrop of the Vicksburg deposits.

In the early days fossil palm wood was referred to the genera Fasciculites Cotta and Endogenites Brongniart or Palmacites Brongniart, but Schenk, who made extensive contributions to this subject, united all the remains in the comprehensive form genus Palmoxylon, in which he has been followed by most subsequent writers. More recently two other German students, Felix and Stenzel, have devoted much time to the elucidation of petrified palm wood from various parts of the world. Stenzel has given us the most comprehensive work on the subject [1] that has yet appeared, in which 62 species of wood and 4 species of roots are elaborately described and figured, and extended comparisons are instituted between the fossil and living species of palms.

The difficulties in the way of satisfactory systematic work on the internal structure of the Monocotyledonæ are very much greater than with the Gymnospermæ or the Dicotyledonæ. Not only are satisfactorily preserved specimens of fossil forms much rarer, by reason of their parenchymatous nature, but there is less characteristic generic variation among the palms, and furthermore the present state of our knowledge of the anatomy of the existing species is in a very unsatisfactory condition.

Felix, in his studies, divided palm woods into two sections—one in which small round sclerenchyma bundles are scattered through the stem parenchyma between the fibrovascular bundles, and one in which these auxiliary sclerenchyma bundles are lacking. Stenzel departs somewhat from this older method and uses a system based largely on a comparison of the arrangement, size, and structure of the bundles in the central and peripheral portions of the stem, and on the size and shape of the sclerenchyma portion of the fibrovascular bundles.

In the present connection no attempt is made to review the literature on fossil palms or on the anatomy of recent palms, the arrangement and supposed affinities as determined by Stenzel being followed without any attempts at revision. The following key will facilitate the determination of remains of this sort:

[1] Stenzel, K. G., Fossile Palmenhölzer: Beitr. Pal. Geol. Österreich-Ungarns u. des Orients, vol. 16, pt. 4, pp. 1-182, pls. 1-22, 1904.

Key of Oligocene species of Palmoxylon of southern United States.

Fibrovascular bundles all similar—that is, without perceptible differences between those of the central and peripheral regions of the stem; parenchyma without intercellular spaces:
- Sclerenchyma portion orbicular or ovate in cross section, either truncate or with a broad, shallow indentation where it joins the vascular portion (reniform)................................*ovatum.*
- Sclerenchyma portion deeply excavated (lunate) to receive the vascular portion, which is approximately equal to it in size. Fibrovascular bundles thin, 0.5 millimeter, close-set, uniformly distributed. No auxiliary bundles..*mississippense.*

Fibrovascular bundles usually crowded in the peripheral region, more remote centrally; sclerenchyma portion strongly developed, usually much larger than the vascular portion:
- Parenchymatous groundmass with intercellular spaces:
  - With auxiliary sclerenchyma bundles:
    - Fibrovascular bundles unsymmetrically arranged, crowded, sclerenchyma portion round. Auxiliary bundles rare, naked. Intercellular spaces not well defined in peripheral portion of stem..............................*texense.*
    - Auxiliary bundles numerous, thin, naked. Parenchyma with prominent intercellular spaces............*lacunosum.*
  - Without auxiliary sclerenchyma bundles:
    - Sclerenchyma portion of fibrovascular bundles sagittate or almost surrounding the reduced vascular portion...*cellulosum.*
    - Vascular portion orbicular or ovate, not in an embayment of the sclerenchyma portion; where the latter joins the former it is flattened (complanate)..*remotum.*
- Groundmass without intercellular spaces..*microxylon.*

Corypha-like stems.

Group SAGITTATA.

Palmoxylon microxylon (Corda) Stenzel.

Palmacites microxylon. Corda, Beiträge zur Flora der Vorwelt, p. 48, pl. 21, 1845.

Fasciculites Cottæ. Unger, Genera et species plantarum fossilium, p. 335, 1850.

Fasciculites didymosolen. Stenzel, De trunco palmarum fossilium (Inaug. diss.), p. 8, 1850.

Palmoxylon Quenstedti. Felix, Die fossile Hölzer Westindiens, p. 25, pl. 4, fig. 4, 1883.

Palmoxylon Quenstedti. Knowlton, U. S. Nat. Mus. Proc., vol. 11, p. 90, pl. 30, fig. 1, 1888.

Palmoxylon microxylon. Stenzel, Fossile Palmenhölzer, p. 68 (174), pl. 15 (17), figs. 160, 168, 1904.

Fibrovascular bundles thick, numerous, closely spaced, irregular in outline in transverse sections, 0.5 to 1 millimeter in diameter; the sclerenchyma portion strongly developed, consisting of exceedingly thick walled cells, often nearly and sometimes entirely surrounding the vascular portion, which consists of a few large or several small vessels; the phloem and xylem parenchyma often poorly preserved. The vascular portion generally occupies a usually angular and often narrow indentation in the basal portion of the handle. Bundles somewhat less numerous in central part of stem. Auxiliary sclerenchymatous bundles numerous, relatively stout, 0.16 to 0.08 millimeter in diameter, not surrounded by a ring of small, longitudinally elongated parenchymatous cells. Groundmass without well-defined intercellular spaces; made up of rather small, thin-walled, usually longitudinally elongated, occasionally isodiametric and parenchymatous polyhedral cells; those in close proximity to bundles radially widened.

This species has been fully discussed by Stenzel. It was described as early as 1845 by Corda from material found in the Oligocene of the island of Antigua and was collected in 1885 by L. C. Johnson in Rapides Parish, La., the exact locality being unrecorded. It has not been found in this region by the more recent collectors.

Occurrence: Catahoula sandstone, Rapides Parish, La.

Collection: United States National Museum.

Palmoxylon cellulosum Knowlton.

Palmoxylon cellulosum. Knowlton, U. S. Nat. Mus. Proc., vol. 11, p. 90, pl. 30, fig. 2, 1888.
Palmoxylon cellulosum. Felix, Fossile Hölzer von Tlacolula, p. 3 (46), pl. 3, figs. 1-3, 1893.
Palmoxylon cellulosum. Stenzel, Fossile Palmenhölzer, p. 72 (178), pl. 15 (17), figs. 169-171; pl. 16 (18), figs. 172-184, 1904.

Fibrovascular bundles large, elliptical in transverse section, about 1 millimeter in diameter; sclerenchyma portion nearly surrounding the vascular portion. Groundmass of large irregular parenchymatous cells, with large intercellular spaces; somewhat more compact in the immediate vicinity of the bundles. The fibrovascular bundles are more numerous in the peripheral than in the central part of the stem, but much less crowded than in *Palmoxylon microxylon.* The ground tissue greatly resembles that of *P. lacunosum* but lacks the auxiliary sclerenchyma bundles of that species.

Palmoxylon cellulosum, as described by Knowlton, came from Rapides Parish, La. Subsequently it was recorded from the State of Oaxaca, Mexico, by Felix, who supposed the strata containing it to be Cretaceous. Either the age determination of the Mexican strata was erroneous or the two occurrences can not represent the same species. Additional material of this species has been collected from Bayou Pierre in Mississippi.

Occurrence: Catahoula sandstone, Rapides Parish, La.; Bayou Pierre, Claiborne-Copiah county line, Miss.

Collection: United States National Museum.

Group COMPLANATA.

Palmoxylon texense Stenzel.

Plate LVI.

Palmoxylon texense. Stenzel, Fossile Palmenhölzer, p. 79 (185), pl. 6 (8), figs. 61-63, 1894.

Stenzel correlated two specimens from Texas with this species, regarding one as a peripheral part of a stem and the other as a more central portion. These he describes as follows:

The ground tissue in both is formed from thin-walled cells; the exterior is dense or at least without well-defined intercellular spaces. The sclerenchyma portion of the longitudinal bundle is surrounded with two or three layers of rather small elongated cells, arranged with their major axes parallel, followed by larger elongated cells which are radially disposed with their short sides toward the fibrous tissue. In the woody fiber, on the contrary, the cells are almost uniformly polygonal; only in isolated areas do any number of even slightly elongated cells occur. The fundamental tissue from the central part of the stem is, on the other hand, porous, with numerous intercellular spaces. Pressed close against the sclerenchyma portion, as in the outer bundles, are well-developed elongated cells which radiate from the woody part, and outside of these are several layers of similar cells connected with each other, which often exhibit a symmetrical orientation toward the middle of the stem.

The outer longitudinal fibrovascular bundles run straight upward; they are placed near one another—in fact, whole series lie so close that they are almost in contact, and 45 or 50 are crowded into a single square centimeter. Within they even lie on top of one another, but toward the middle of the stem they are separated by interspaces two or three times their own thickness, so that only a dozen fibrovascular bundles occur in the same space; and yet almost all the longitudinal bundles, like the small transverse bundles, direct their sclerenchyma portion, sometimes horizontally, sometimes a little obliquely, toward the exterior, so that we must take it for granted that we have before us, in addition, a part of the intermediate layer. It is very remarkable that among the outer longitudinal bundles only a small fraction are unsymmetrically arranged.

The longitudinal bundles are obviously binary. The roundish sclerenchyma portion, of very thick walled cells, is somewhat flattened toward the inside, even squeezed very thin, but laterally it is rounded. At this point the smaller vascular portion is generally attached; this is usually elongated near the outer bundles and frequently produced behind so that it appears almost triangular in outline, while within it is rounded to form a semicircle in cross section. It bears two discrete vascular bundles either one of which may be replaced by two others, similar in character, situated near at hand.

The transverse bundles, in which the breadth of the fibrous portion is equal to or less than the breadth of the longitudinal bundles, have a simple yet narrower, more produced woody portion.

The few auxiliary sclerenchyma bundles are of not more than medium thickness. They are uniformly distributed, thin, and without encircling cells.

Stenzel does not give the exact locality in Texas where his material was collected, but it is not unlikely to have come from the same area in Jasper County as my material. Unstudied material indicates the probable presence of this species at several localities in the Catahoula sandstone of Texas and in the Vicksburg limestone of Alabama.

Occurrence: Catahoula sandstone, 5 miles north of Jasper, Jasper County, Tex.

Collection: United States National Museum.

Palmoxylon lacunosum (Unger) Felix.

Plate LVII, figure 1; Plate LVIII.

Fasciculites lacunosus. Unger, in Martius, Genera et species palmarum, vol. 1, p. 58, sec. 16, tab. geol. 1, fig. 1; 2, fig. 8; 3, fig. 1, 1845; Synopsis plantarum fossilium, p. 186, 1845; Chloris protogæa, p. 71, 1845; Genera et species plantarum fossilium, p. 335, 1850.

Palmoxylon lacunosum. Felix, Die fossile Hölzer Westindiens, p. 23, pl. 5, fig. 3, 1883. [1882 name is referred by Stenzel to *P. anomalum* (Unger).]

Palmoxylon lacunosum. Stenzel, Fossile Palmenhölzer, p. 81 (187), pl. 8 (6), figs. 64–66, 1904.

Palmoxylon lacunosum. Schenk, in Zittel, Handbuch der Palaeontologie, Abth. 2, Palaeophytologie, p. 889, fig. 430, 1890.

Fibrovascular bundles not crowded, especially in interior of stem; sclerenchyma portion ovate or reniform in transverse section. Vascular portion orbicular. Auxiliary sclerenchyma, bundles numerous, thin, without modified encircling cells. Groundmass with intercellular spaces, which are not greatly developed in the peripheral part of the stem.

Stenzel refers the following forms to this species:

Fasciculites anomalus. Unger, in Martius, op. cit., p. 57, pl. 2, fig. 9; pl. 3, fig. 2, 1845. (This reference, if correct, would, according to the law of priority, involve a change in the name of this well-known form.)

Palmacites axonensis. Watelet, Plantes fossiles du bassin de Paris, p. 103, pl. 30, fig. 3, 1866. (From Quincy-sous-le Mont, in the valley of the Aisne.)

The species is close to *Palmoxylon texense* and also to *P. antiguense.* The original locality is unknown, although the species is often referred to the island of Antigua, as by Schenk. My Catahoula material is abundant, but not especially well preserved. Very well preserved material occurs in the Vicksburg at Nero, Ala.

Occurrence: Catahoula sandstone, Texas & Pacific Railway, 1 mile east of Galbraith, northwest border of Rapides Parish, La.; south bank of creek just north of Pollock, Grant Parish, La.

Collection: United States National Museum.

Palmoxylon remotum Stenzel.

Plate LVII, figures 2–5.

Palmoxylon remotum. Stenzel, Fossile Palmenhölzer, p. 91 (197), pl. 7 (9), figs. 79–81; pl. 8 (10), fig. 82; pl. 9 (11), figs. 83–85, 1904.

Fibrovascular bundles thick, 1 millimeter in diameter, rather widely spaced; sclerenchyma portion elliptical to reniform in transverse section, flattened where it joins the orbicular relatively large vascular portion, which consists of a few large vessels and several small ones. Auxiliary sclerenchyma bundles wanting. Groundmass of elongated cells with intercellular spaces, except in the immediate vicinity of the fibrovascular bundles, where they are closer and radiately arranged.

This species is readily distinguished from associated forms by the large size and remoteness of the fibrovascular bundles, coupled with the absence of auxiliary bundles. It was described by Stenzel from specimens collected near Washington, Adams County, Miss. I discovered a fragment over 30 centimeters in diameter and 75 centimeters in length in the possession of a native of Waynesboro, in the eastern part of Mississippi. It was collected from the surface of the ground about 5 miles north of Waynesboro, in a depression of the Vicksburg limestone and is now in the collection of the Geological Survey of Mississippi. Dr. E. N. Lowe, the State geologist, kindly forwarded fragments to me for study.

Occurrence: Catahoula sandstone, Washington, Adams County, Miss.; 5 miles north of Waynesboro, Wayne County, Miss.

Collections: United States National Museum, Mississippi Geological Survey, Gustav Stenzel in Breslau.

Cocos-like stems.

Group LUNARIA.

Palmoxylon mississippense Stenzel.

Palmoxylon mississippense. Stenzel, Fossile Palmenhölzer, p. 142 (248), pl. 21 (23), figs. 254–265, 1904.

I have not seen any specimens of this species, and the following is a free translation of some of Stenzel's comments on it:

The curved and irregular course of the longitudinal bundles, as well as the change in relative position of sclerenchyma and vascular portions, the relatively large size of the vascular portion, which equals that of the sclerenchyma portion, and the slight disparity between the size of the transverse and that of the longitudinal bundles all give evidence of the fact that the specimen is from the central part of a stem.

The groundmass consists of thin-walled, closely locked cells which are small and elongated only in proximity to the fibrovascular bundles and in the narrow interspaces between two adjacent bundles; elsewhere they are polygonal and reach 0.04 millimeter in width.

The longitudinal bundles are uniformly distributed and are separated from each other by interspaces approximately equal to their semidiameter, though occasionally they stand farther apart. At the same time they are so small, with a maximum diameter of scarcely 1 to 2 millimeters, that as many as 300 have been found in 1 square centimeter.

Because of the very different directions in which they are turned, more than one-half lie within a quarter circle, so that these can be looked upon as directed toward the exterior; the directions of the cross and of the transverse bundles are, however, very diverse, and the course of the bundles is bent now this way and now that, so that the most plausible theory still seems to be that we have before us a part of the central portion of the stem. This would also accord with the assumption that this belongs to a Cocos-like form.

The outline of the longitudinal bundle is somewhat distorted in the figures, and the oval as well as the cross and the various oblique sections of the same bear witness to the weathering of the fossil, as does also the frequent pitting of the veins and even more strongly the discrepant stratification of the bundles. Then, too, we find that the vascular portions of the bundles, which are ordinarily pressed flat against the sclerenchyma portions, have been warped to one side just as we have seen them elsewhere.

These same causes account for the polymorphism of the sclerenchyma portion in the groundmass, in which we find as a prevailing peculiarity that the outer boundary is a semicircle, while within it borders upon the vascular bundle with an almost horizontal contact line excepting for a flattened contraction near the middle. In many bundles this contraction is more sharply defined, its margins more angular, and it is often more restricted on one side than on the other. In only a few is the margin obtuse or even somewhat rounded. In that case the ordinary lunar outline is not wholly obscured. The cells of the sclerenchyma portion are uniform and polygonal, with thickened walls, leaving, however, a moderately large lumen.

This species is very similar to *Palmoxylon palmacites* (Sprengel) Stenzel,[1] which occurs in the Oligocene of Antigua and of the Canal Zone.

Occurrence: Catahoula sandstone, Washington, Adams County, Miss.

Collection: Gustav Stenzel in Breslau.

Group RENIFORMIA.

Palmoxylon ovatum Stenzel.

Palmoxylon ovatum. Stenzel, Fossile Palmenhölzer, p. 119 (225), pl. 14 (16), figs. 152–158, pl. 15 (17), fig. 159, 1904.

This species, like *Palmoxylon mississippense,* is unrepresented outside of Prof. Stenzel's collection. It may be briefly described as follows:

Fibrovascular bundles thick, closely and somewhat irregularly spaced; sclerenchyma portion orbicular, ovate or elliptical in transverse section, truncated or with a shallow indentation where it joins the vascular portion, which is well developed and often as large as the sclerenchyma portion; rhomboidal in transverse outline. Auxiliary bundles not abundant, without modified encircling cells. Groundmass without intercellular spaces. A distinguishing feature of this species is the occurrence in transverse sections of tiny scattered dark spots resembling the smaller auxiliary sclerenchyma bundles of *Palmoxylon lacunosum.* They show no structure and often lie in juxtaposition with the fibrovascular or auxiliary bundles.

Stenzel compares the structure of this form with that of existing forms of Mauritia and Geonoma. Among fossil species it is said to be most similar to *Palmoxylon cottæ* (Unger) Felix, a species occurring in the Oligocene of the West Indies and Italy and in the upper Eocene or lower Oligocene of Egypt (Libya).

Occurrence: Catahoula sandstone, Washington, Adams County, Miss.

Collection: Gustav Stenzel in Breslau.

[1] Stenzel, Gustav, Fossile Palmenhölzer, p. 245, pl. 20, fig. 253, 1904.

Subclass DICOTYLEDONÆ.

Order URTICALES.

Family MORACEÆ.

Genus FICUS Linné.

Ficus sp.

Plate LV, figure 9.

The remains of a single fruit of some species of Ficus is contained in the collections from the argillaceous sandstones of the Chalk Hills, La. It may be characterized as follows: Fruit obovate in lateral view, circular in cross section, with a rounded apex, tapering downward to the short and thick peduncle. Length about 2.5 centimeters; maximum diameter in the upper part, about 1.5 centimeters. Peduncle about 4 millimeters in length. Outer surface rough with irregular longitudinal ridges. Texture somewhat leathery.

This fruit clearly represents a small, semifleshy fruit of some species of fig, as yet unrepresented by foliage, which flourished on the Vicksburg strand. It is closely comparable with the fruits of many existing species of figs and is not unlike several fossil fruits which have been described. As the majority of fossil species are based on foliage, which is exceedingly abundant in Tertiary floras everywhere, I have not ventured to give the present form a specific name.

Occurrence: Catahoula sandstone, Chalk Hills 2 miles south of Rosefield, La.

Collection: New York Botanical Garden.

Order PROTEALES.

Family PROTEACEÆ.

Genus EMBOTHRITES Unger.

Embothrites ungeri Berry, n. sp.

Plate LV, figures 11, 12.

Seed unsymmetrical, roughly triangular in outline, somewhat flattened, produced into a conical point at the chalazal end, rounded distad and at the inner angle, where an elliptical hollow represents a depression made by pressure of the adjacent seed. Fruit evidently capsular, as indicated by the contour of the seed, which shows that the capsule contained several closely packed seeds. Seeds winged. Wing rather firm, broad, abruptly rounded, with about 20 thin subparallel longitudinal veins. Length of seed about 7 millimeters; maximum width about 3.5 millimeters. Proximal spur about 1.5 millimeters long. Wing about 7 millimeters wide and 6 millimeters long.

This distinctive winged seed is represented by the single specimen figured, from which the accompanying enlarged drawing has been made. Rather similar winged seeds occur in a number of existing families. The scars on the specimen show that several seeds were formed in a dry fruit—that is, a capsule—and the presence of wings indicates that it was dehiscent. This serves to distinguish the fossil from the samaras of the family Malpighiaceæ, which somewhat resemble it, particularly some modern forms of the genus Banisteria. Several existing forms of Bombacaceæ and Sterculiaceæ also show resemblances. Somewhat similar seeds with very much abbreviated wings have been referred by Heer and others to the genus Pterospermites of the family Sterculiaceæ.

The genus Embothrium Förster, which suggested the name for the fossil genus to Unger, comprises but few existing species of the South American Andean region, ranging from Peru to the Straits of Magellan, and one or two species of the mountains of tropical Western Australia. About a dozen fossil species from the European area, ranging from the upper Oligocene through the Miocene, have been referred to the living genus. Nine or ten fossil species have been referred to Embothrites. These are slightly older than the species referred to Embothrium, ranging from the Ligurian or Sannoisian (basal Oligocene) through the Oligocene into the Aquitanian, which by a number of recent students is made the basal part of the Miocene. All these species are from the European continent, where leaves and seeds are common, no authentic representative having heretofore been discovered in North America, although Hollick[1] has described a Cretaceous leaf under the generic term Embothriopsis, and Lesquereux[2] many years ago described a leaf from the Dakota sandstone of Kansas as *Embothrium? daphneoides*. Neither of these forms is very convincing evidence of the existence of the ances-

[1] Hollick, Arthur, Additions to the paleobotany of the Cretaceous formation on Long Island: New York Bot. Gard. Bull., vol. 8, p. 159, pl. 165, fig. 1, 1912.

[2] Lesquereux, Leo, Contributions to the fossil flora of the Western Territories, pt. 1, The Cretaceous flora, p. 87, pl. 30, fig. 10, 1874.

tors of Embothrium in the Upper Cretaceous flora of North America.

There are three species of seeds from the European Tertiary which especially resemble the present seed. These are *Embothrites aquensis* Saporta,[1] from the Sannoisian of southeastern France; *Embothrites boreale* Unger,[2] the type of the genus, an Aquitanian form of Croatia, Styria, and especially Greece,[3] and *Embothrites leptospermos* Ettingshausen,[4] which ranges from the Sannoisian lignites of Tyrol to the Aquitanian brown coal of Styria. The last is by far the closest to the American species and is well figured in basal Oligocene material from Tyrol.[5] The present species, which differs from all previously described forms in the extent to which the proximal spur is developed, is named in honor of Franz Unger, who first described the genus.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collection: New York Botanical Garden.

Order RANALES.

Family ANONACEÆ.

Genus ANONA Linné.

Anona texana Berry, n. sp.

Plate LX, figure 9.

Leaves of large size, broadly ovate in general outline, with a pointed apex and a rounded base. Length about 15 or 16 centimeters; maximum width about 5.25 centimeters in the lower half of the leaf. From the region of maximum width the leaf narrows upward, but the tip is not extended. Margins entire, slightly undulate. Texture presumably coriaceous, but as these leaves are preserved as impressions in sandstone this is not certain. Petiole short and stout. Midrib stout, prominent on the lower surface of the leaf. Secondaries of considerable size but relatively thin, 8 to 10 pairs, irregularly spaced and usually remote; they diverge from the midrib at varying angles from 60° to 70° and are either regularly curved or relatively straight, camptodrome in the marginal region. A few transversely percurrent tertiaries are visible, but the bulk of the tertiary venation is obsolete. This is a well-marked species of Anona, somewhat resembling but entirely distinct from the various Anona leaves so common in the upper part of the middle Wilcox. It is also very similar to several existing species which are common in the American Tropics.

Occurrence: Fayette sandstone, three-quarters of a mile above the junction of Caney and White Rock creeks, Trinity County, Tex.

Collection: United States National Museum.

Order ROSALES.

Family MIMOSACEÆ.

Genus PITHECOLOBIUM Martius.

Pithecolobium oligocænum Berry, n. sp.

Plate LV, figure 10.

Leaves pinnate, with several pairs of opposite leaflets. Leaflets asymmetric-ovate in outline; widest in the middle part, where the lateral margins are full and rounded; narrowing rapidly both distad and proximad to form the equally pointed apex and base; the ultimate point of the former not acuminate but bluntly rounded. Length about 2.6 centimeters; maximum width about 1.7 centimeters. Margins entire. Texture subcoriaceous. Petiolule short and stout, about 2 millimeters in length. Midrib stout, curved, prominent on the lower surface of the leaflet. Secondaries stout, about five or six subopposite to alternate pairs, diverging from the midrib at angles of about 50°, curving upward, camptodrome in the marginal region, prominent on the lower surface of the leaflet. Tertiaries thin but well marked in the specimens, the meshes being exactly comparable with those of existing species of Pithecolobium with which they have been compared.

The genus Pithecolobium, which is more or less closely related to the genus Inga of Willdenow, has over 100 existing species, all confined to the Torrid Zone and many of them large trees. Three-fourths of the existing species occur in the American Tropics, but there are over a score in the Asiatic Tropics, and a few in the African and Australian Tropics. Up to the time of the present studies the genus had not been recognized in the fossil state. There are two well-marked species in the Wilcox

[1] Saporta, Gaston de, op. cit. (Études, etc.), vol. 1, p. 107, pl. 8, fig. 8, 1863.
[2] Unger, F. J., Die fossile Flora von Sotzka, p. 41, pl. 21, figs. 10–12, 1859.
[3] Unger, F. J., Die fossile Flora von Kumi, p. 37, pl. 9, fig. 23, 1867.
[4] Ettingshausen, Constantin, Die Proteaceen der Vorwelt, p. 19, pl. 2, figs. 12, 13, 1851.
[5] Ettingshausen, Constantin, Die tertiäre Flora von Häring in Tirol, p. 51, pl. 14, figs. 15–25, 1853.

flora of Mississippi and northern Tennessee, and the present species forms a link between these Wilcox species and the trees of the present-day American Tropics that have very similar leaves.

The species is not abundant in the rather small collections from this horizon.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collection: New York Botanical Garden.

Order GERANIALES.

Family RUTACEÆ.

Genus FAGARA Linné.

The genus Fagara consists of numerous existing species of shrubs and trees, over 150 being known. They are cosmopolitan in tropical and subtropical countries and a few range into the Temperate Zone, especially in southeastern North America, where they have been confused with the closely allied genus Xanthoxylum Linné. Fossil forms based on foliage are usually referred to Xanthoxylum, and these number about 20 species, all of Tertiary age, mostly from the European Oligocene. The leaves in the two genera are much alike, the main distinction being the absence of a calyx in Xanthoxylum. This would indicate that Xanthoxylum is derived from Fagara by reduction of floral parts and by adaptation to cooler climates. I have elsewhere expressed the opinion that this evolution had not occurred in Eocene time, and I have described several species of Figara from the Upper Cretaceous and lower and middle Eocene of the Mississippi embayment. These species appear to be ancestral to the numerous representatives of this genus found in the lower Oligocene of Louisiana. The more argillaceous lenses in this lower part of the Vicksburg limestone in central Louisiana are crowded with leaflets of the Fagara type, suggesting the lagoons of southern Florida, where calcareous muds are accumulating and in the vicinity of which species of Fagara are among the commonest of coastal plants, as they are also throughout the Antilles and in Central America and northern South America.

The Oligocene material is diverse and might be differentiated into a score of species or described as one species according to the mental attitude of the student. After much study I have differentiated four forms as varieties of a central type for which the name *Fagara catahoulensis* is proposed. They are differentiated by characters which appear to be constant, notwithstanding the fact that all are represented by numerous specimens. They are all more or less inequilateral glandular punctate leaves, with grooved petiolules and a tendency toward revolute margins—all characters suggesting the Rutaceæ and distinguishing them from various genera of the Rhamnaceæ with which they might otherwise be compared. Their punctate character is well shown in some of the photographs reproduced in the present work.

Key to American Oligocene forms of Fagara.

Leaflets orbicular or elliptical. Secondaries few, five pairs or less.............*Fagara catahoulensis orbiculata.*
Leaflets ovate or ovate-lanceolate:
  Twice as long as wide, broadest midway between apex and base. Secondaries numerous, more than five pairs...............*Fagara catahoulensis elongata.*
  Less than twice as long as wide:
    Secondaries few, five pairs or less, *Fagara catahoulensis coriacea.*
    Secondaries numerous, more than five pairs, *Faga catahoulensis major.*

Fagara catahoulensis orbiculata Berry, n. var.

Plate LIX, figures 1–3.

Leaflets glandular punctate, of medium size for this genus, orbicular or elliptical in general outline, equally rounded at the apex and base. Length from 2.5 to 4 centimeters; maximum width, midway between the apex and the base, from 1.8 to 3.3 centimeters. Margins entire. Texture coriaceous. Petiolule short, stout, grooved, curved, about 3 millimeters in length. Midrib stout, curved or flexuous, prominent on the lower surface of the leaflet. Secondaries stout, prominent on the lower surface of the leaflet, four or five subopposite to alternate pairs, diverging from the midrib at angles ranging from 65° in the lower part of the orbicular leaflets to 35° in the upper part of some of the orbicular leaflets and in the elliptical leaflets; all camptodrome, usually at a considerable distance from the margin. Tertiaries thin but well marked, especially on the lower surface of the leaflets, forming open irregular meshes that are well shown in the small elliptical leaflet figured. Areolation of thin but distinct veinlets forming minute quadrangular or polygonal meshes.

This form shows considerable variation from the typical orbicular leaflet figured, through the large leaflet in which the apex is somewhat ascending, toward *Fagara catahoulensis major*, and on the other hand the elliptical forms like the one figured approach *Fagara catahoulensis elongata*. These variants of *orbiculata* differ from both of these other forms in the fewer and more open secondaries and in their general outline, as is readily seen in the photographic reproductions of some of the specimens. They are much less common than any of the associated forms of Fagara.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.; Fayette sandstone, Stryker, Tex.

Collections: United States National Museum, New York Botanical Garden.

Fagara catahoulensis coriacea Berry, n. var.

Plate LIX, figures 8–10.

Leaflets glandular punctate, of small size, ovate-lanceolate, and slightly inequilateral in general outline, with a bluntly pointed apex and a broadly rounded base. Length from 1.75 to 2.75 centimeters, averaging about 2 centimeters; maximum width, below the middle of the leaflet, from 1.2 to 2 centimeters, averaging about 1.4 centimeters. Margins entire, slightly revolute in some specimens. Texture coriaceous. Petiolule very stout, grooved, curved, 3.5 millimeters in length. Midrib stout and curved, prominent on the lower surface of the leaflet. Secondaries stout and prominent, four or five mostly subopposite pairs; they diverge from the midrib at somewhat irregular intervals at angles ranging from 35° to 60°, and pursue a straight course halfway to the margins where they curve upward; camptodrome in the marginal region. Tertiaries immersed in the leaf substance.

This well-marked form is less abundant in the collections than *elongata* or *major* but more abundant than *orbiculata*. It is much like *major* in general outline but is broader nearer the base, has fewer secondaries, and averages much smaller in size.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collection: New York Botanical Garden.

Fagara catahoulensis major Berry, n. var.

Plate LIX, figures 4–7.

Leaflets glandular punctate, averaging of relatively large size, ovate-lanceolate and slightly inequilateral in outline, with an acutely pointed apex and a rounded or broadly pointed base. Length from 2.2 to 4.5 centimeters, averaging about 3.5 centimeters; maximum width, at or slightly below the middle, from 1.5 to 2.75 centimeters, averaging about 2.5 centimeters. Margins entire. Texture coriaceous. Petiolule stout, grooved, about 4.5 millimeters in length, in some specimens showing evidence of narrow, straight lateral wings. Midrib stout, prominent on the lower surface of the leaflet. Secondaries stout and prominent, about six pairs, subopposite below and usually alternate above; they diverge from the midrib at angles of about 45°, although there is considerable variation in this feature; they are for the most part regularly curved upward and subparallel and are camptodrome in the marginal region. Tertiaries mostly immersed in the leaf substance; a few percurrent ones visible.

This is the most common as well as the largest form in the collection and is represented by abundant material. It approaches *elongata* on the one hand and *coriacea*, as well as some of the more elongated forms of *orbiculata*, on the other.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collections: United States National Museum, New York Botanical Garden.

Fagara catahoulensis elongata Berry, n. var.

Plate LIX, figures 11–15.

Leaflets glandular punctate, averaging of rather small size, narrowly ovate and inequilateral in general outline, nearly equally pointed at the apex and base, the apex sometimes slightly more pointed than the base. Length from 1.6 to 4.25 centimeters, averaging about 2.75 centimeters; maximum width, midway between the apex and the base, from 1 to 2 centimeters, averaging about 1.4 centimeters. Margins entire, slightly revolute. Texture coriaceous. Petiolule stout, grooved, curved, enlarged proximad, 3 to 4 millimeters in length. Midrib stout, usually curved, prominent on the lower surface of the leaflet. Secondaries stout, six or seven subopposite to alternate pairs, diverging from the midrib at angles of about 40°, subparallel, camptodrome in the marginal region. Tertiaries immersed in the leaf substance.

This form is more abundant than the varieties *orbiculata* and *coriacea*, but not as abundant as *Fagara catahoulensis major*. It resembles some of the forms of *orbiculata* as well as some of the variants of *major* but differs from both of these in its proportions.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.; Fayette sandstone, Stryker, Tex.

Collections: United States National Museum, New York Botanical Garden.

Order RHAMNALES.

Family RHAMNACEÆ.

Genus PALIURUS Jussieu.

Paliurus catahoulensis Berry, n. sp.

Plate LX, figures 1–4.

Leaves of small size, ovate to oblong-lanceolate in general outline, with a narrowed and acutely or bluntly pointed tip and a broadly rounded, somewhat inequilateral base. Length from 2.5 to 5 centimeters, averaging about 3 centimeters; maximum width, in the lower half of the leaf, from 7 millimeters to 2 centimeters. Margins entire. Leaf substance thin but apparently of considerable consistency. Petiole short, stout, and curved, about 2 millimeters in length. Midrib slender, somewhat flexuous. Lateral primaries thin, one on each side, diverging from the top of the petiole and forming an angle of 35° with the midrib, curving upward parallel with the lateral leaf margin and becoming parallel with the midrib, extending above the middle of the leaf, terminating by joining a secondary. Secondaries thin, three or four subopposite to alternate pairs in the upper half of the leaf, diverging from the midrib at angles of about 50°, curved regularly upward, camptodrome in the marginal region. Tertiaries forming open camptodrome arches from the outside of the lateral primaries in the marginal region; internally they are thin, numerous, transverse in direction, nearly straight or inosculating.

This well-marked species has smaller leaves than the majority of described fossil species, but it may be matched by several existing forms in this and the allied genus Zizyphus.

In the existing flora Paliurus is represented by two species, one confined to China and Japan and the other extending westward into southern Europe. About 30 fossil species based on both leaves and the characteristic fruits are known, some of which extend back in time to the middle Cretaceous. Zizyphus, which in the absence of fruiting specimens is not distinguishable with certainty from Paliurus, has about 40 existing species confined largely to the Indo-Malayan Tropics, only a single species occurring in the American Tropics. It has numerous fossil species. Both genera are well represented in the Eocene floras of the Mississippi embayment.

At the same locality and horizon which furnished the leaves a fragment of a slender flexuous thorned stem was collected. While I realize that this might belong to a variety of unallied genera, its character and association have led me to refer it tentatively to this species. It may be compared with the almost identical remains from the Sannoisian of Aix, in southeastern France, which Saporta[1] referred to *Paliurus tenuifolius* Heer.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collection: New York Botanical Garden.

Order MYRTALES.

Family MYRTACEÆ.

Genus MYRCIA De Candolle.

Myrcia catahoulensis Berry, n. sp.

Plate LX, figures 5, 6.

Leaves of small size, linear-lanceolate, and often somewhat falcate in general outline, with a gradually narrowed and acuminate apex and a similarly pointed base. Length from 4.5 to 7 centimeters; maximum width, in the middle part of the leaf, 5 millimeters to 1.1 centimeters. Margins entire. Texture coriaceous. Petiole missing. Midrib stout, somewhat prominent on the lower surface of the leaf. Secondaries thin, immersed in the substance of the leaf and seen only with difficulty,

[1] Saporta, Gaston de, op. cit. (Études, etc.), vol. 3, suppl. 1, p. 98, pl. 16, figs. 12, 13, 1867.

their tips joined by an acrodrome marginal vein on each side close to the margin and, like the secondaries, nearly obsolete by immersion in the leaf substance.

This species is represented by several fragmentary specimens in the Chalk Hills collection, two of which, showing the extremes of size, are figured. The oldest beds in which the genus has been definitely recognized are those of the Wilcox group, but it is probably represented in Upper Cretaceous floras by some of the forms referred to the genus Eucalyptus. It is an abundant element in the Wilcox flora, being represented by four described species, among which *Myrcia bentonensis* Berry, a form found along the shores of the Mississippi embayment from central Arkansas to northern Mississippi, is most like the present species. It is, however, always larger, usually much larger, and is more obtusely pointed.

The genus Myrcia is the most varied existing American genus of the Myrtaceæ, having more than 400 tropical species, massed in northern South America, but extending southward to Uruguay and Chile and northward through the West Indies. The present fossil form may be compared with a number of still-existing American species, and it is evident that the genus was present in the flora of tropical and subtropical America from the dawn of the Eocene down to the present time, invariably extending its range northward over southeastern North America whenever the climatic conditions were favorable.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collections: United States National Museum, New York Botanical Garden.

Order EBENALES.

Family SAPOTACEÆ.

Genus BUMELIA Swartz.

Bumelia vicksburgensis Berry, n. sp.

Plate LX, figure 7.

Leaves of small size, elliptical, almost orbicular in general outline, with an emarginate tip and a broadly rounded base. Length about 1.2 centimeters; maximum width, at a point about midway between the apex and the base, about 1 centimeter. Margins entire, inclined to be slightly revolute. Texture very coriaceous. Petiole wanting. Midrib stout, slightly curved. Secondaries thin, immersed in the leaf substance, four or five pairs, diverging from the midrib at wide angles and camptodrome in the marginal region. Tertiaries completely immersed.

The present species is small for this genus and superficially resembles various leguminous leaflets such as those of the genera Dalbergia and Colutea.

The genus Bumelia is confined to America in the existing flora and comprises about 20 species scattered from the southern United States through the West Indies and Central America to Brazil. Its geologic history ranges from the Upper Cretaceous to the present and although it is exclusively American in the Recent flora it is well represented in the European Tertiary. There are four well-marked species in the flora of the Wilcox group, one of which, *Bumelia pseudohorrida* Berry, is very similar to the present species. Among recent species *Bumelia horrida* Grisebach, of the West Indies, is close to the present species, its chief difference being the possession of a petiole.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collection: New York Botanical Garden.

Genus CARPOLITHUS Stokes and Webb.

Carpolithus bumeliaformis Berry, n. sp.

Plate LX, figure 8.

Fruit oblate-spheroidal, nearly globose, about 7.5 millimeters in maximum diameter (length) and 5.75 millimeters in minimum diameter. Seed large, nearly globose, crustaceous; flesh thin and dry.

The present species is based on only a few specimens which agree remarkably well with the fallen fruits of those of our American species of Bumelia that have dry instead of fleshy fruits.

The genus Bumelia is a prominent element in the earlier Tertiary floras of southeastern North America, the leaves of one species being associated with the present fruits. As the nature of the remains precludes certainty of identification I have referred these fruits to the convenient form genus Carpolithus and have emphasized their supposed botanic affinity in the specific name.

Occurrence: Catahoula sandstone, Chalk Hills, 2 miles south of Rosefield, La.

Collection: New York Botanical Garden.

PLATES LV-LX.

PLATE LV.

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2.	*Pestalozzites minor* Berry. Chalk Hills, La	230
3, 4.	*Lygodium mississippiensis* Berry. Near King, Miss	231
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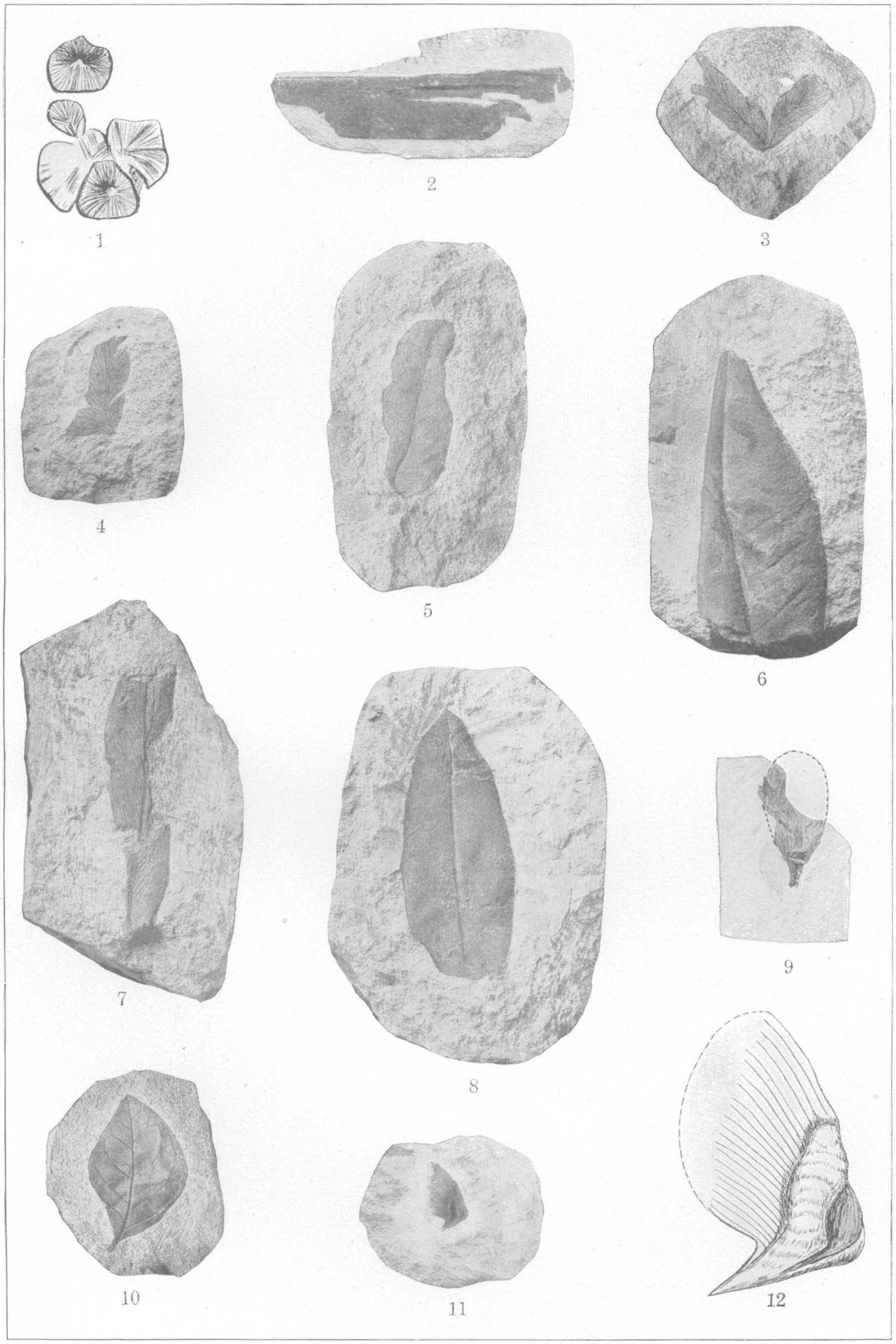
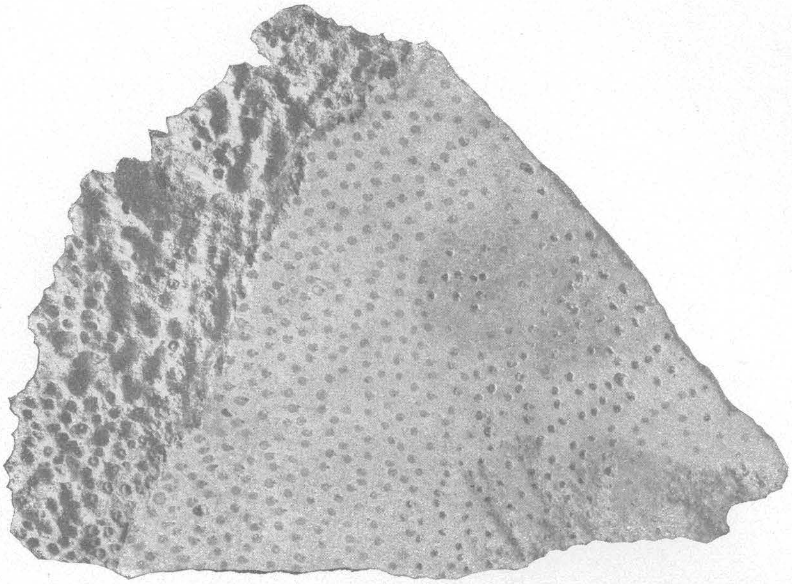
10.	*Pithecolobium oligocænum* Berry. Chalk Hills, La	239
11, 12.	*Embothrites ungeri* Berry. Chalk Hills, La. Figure 12 enlarged four times	238

All from Catahoula sandstone.



FOSSILS OF THE CATAHOULA SANDSTONE.



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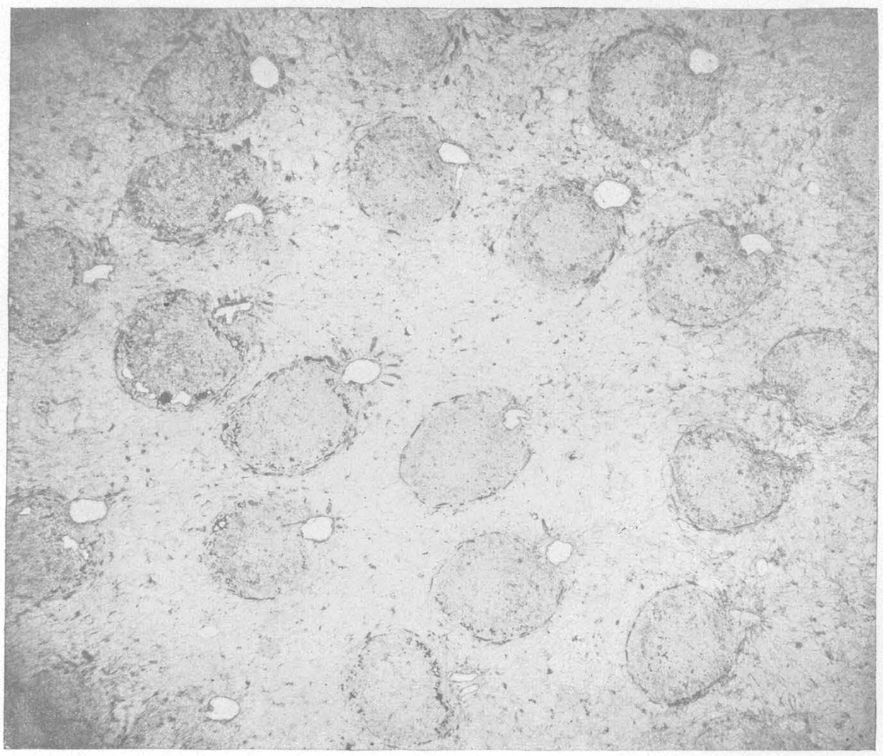

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FOSSILS OF THE CATAHOULA SANDSTONE.

PLATE LVI.

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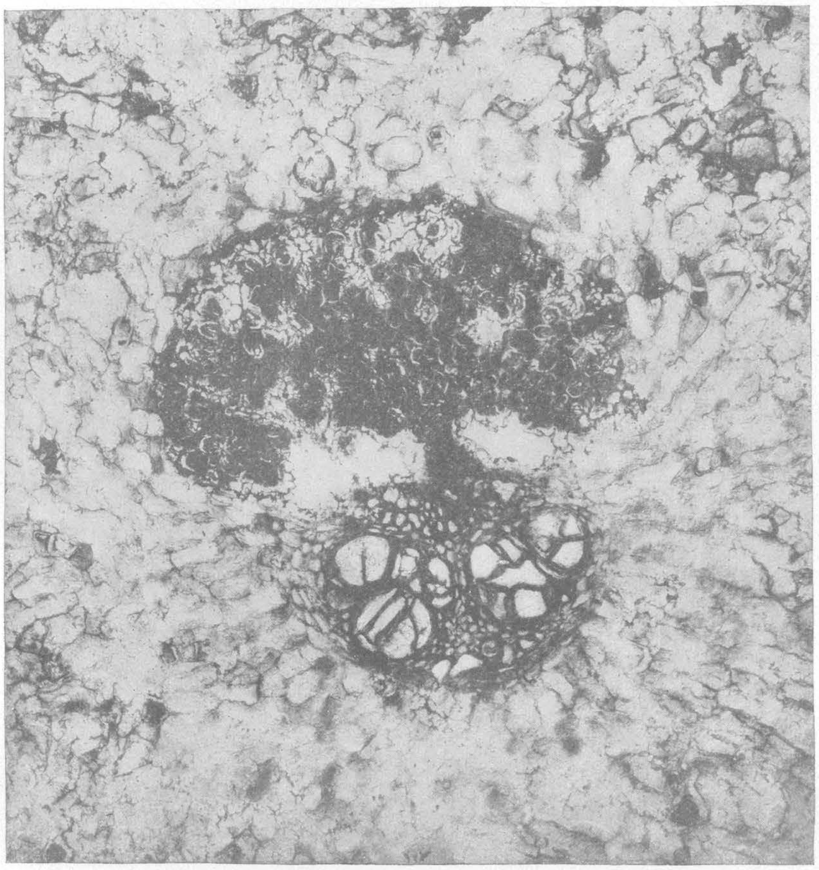
2–5.	*Palmoxylon remotum* Stenzel. Five miles north of Waynesboro, Miss. Showing variations in bundles; enlarged 25 times	236

All from Catahoula sandstone.



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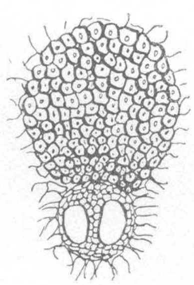

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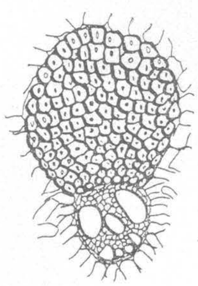

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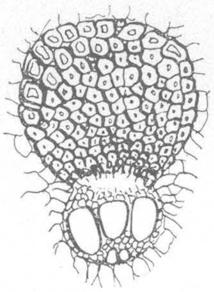

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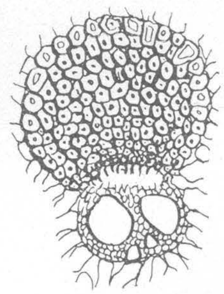

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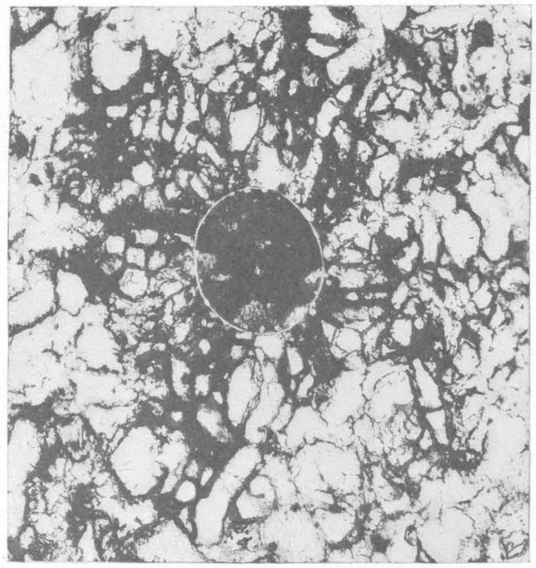

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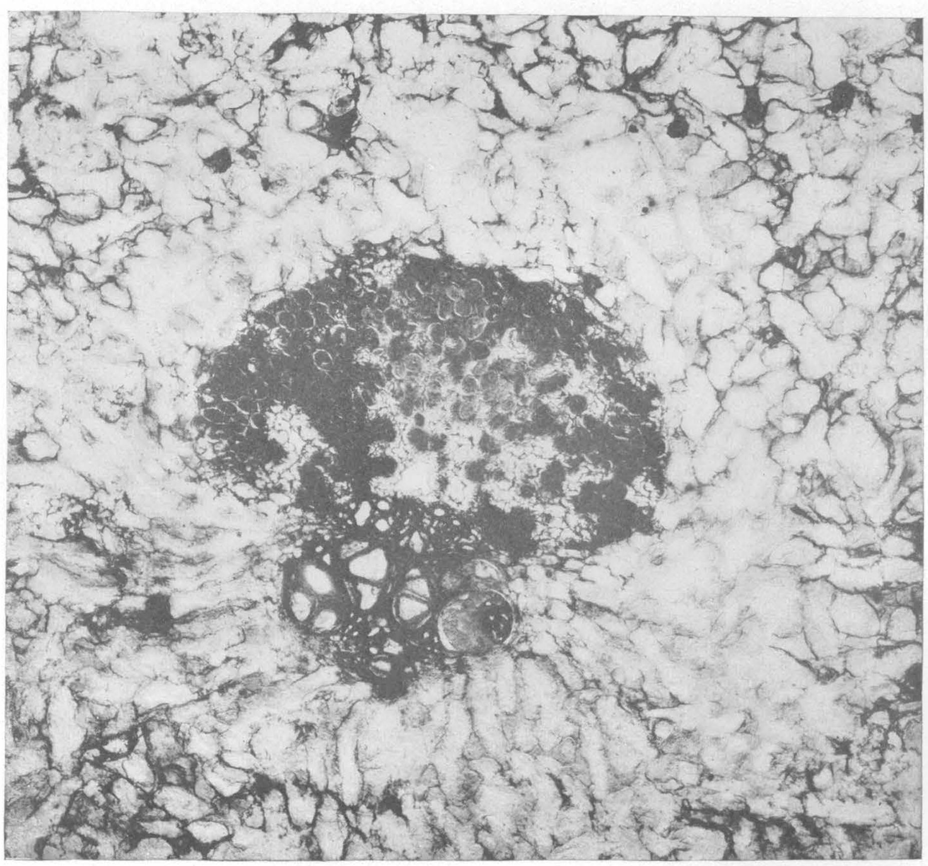

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FOSSILS OF THE CATAHOULA SANDSTONE.

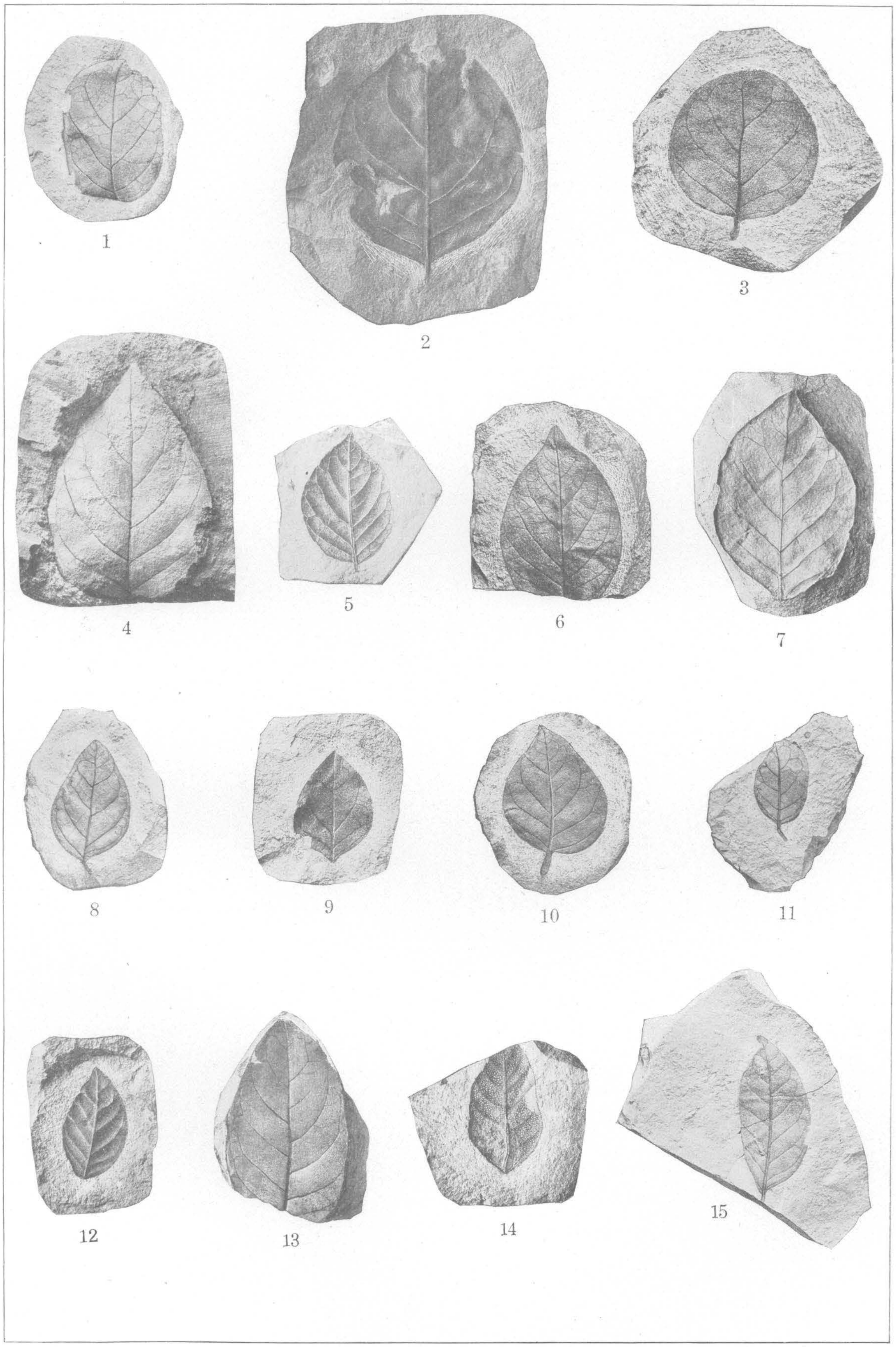
PLATE LVIII.

Page.

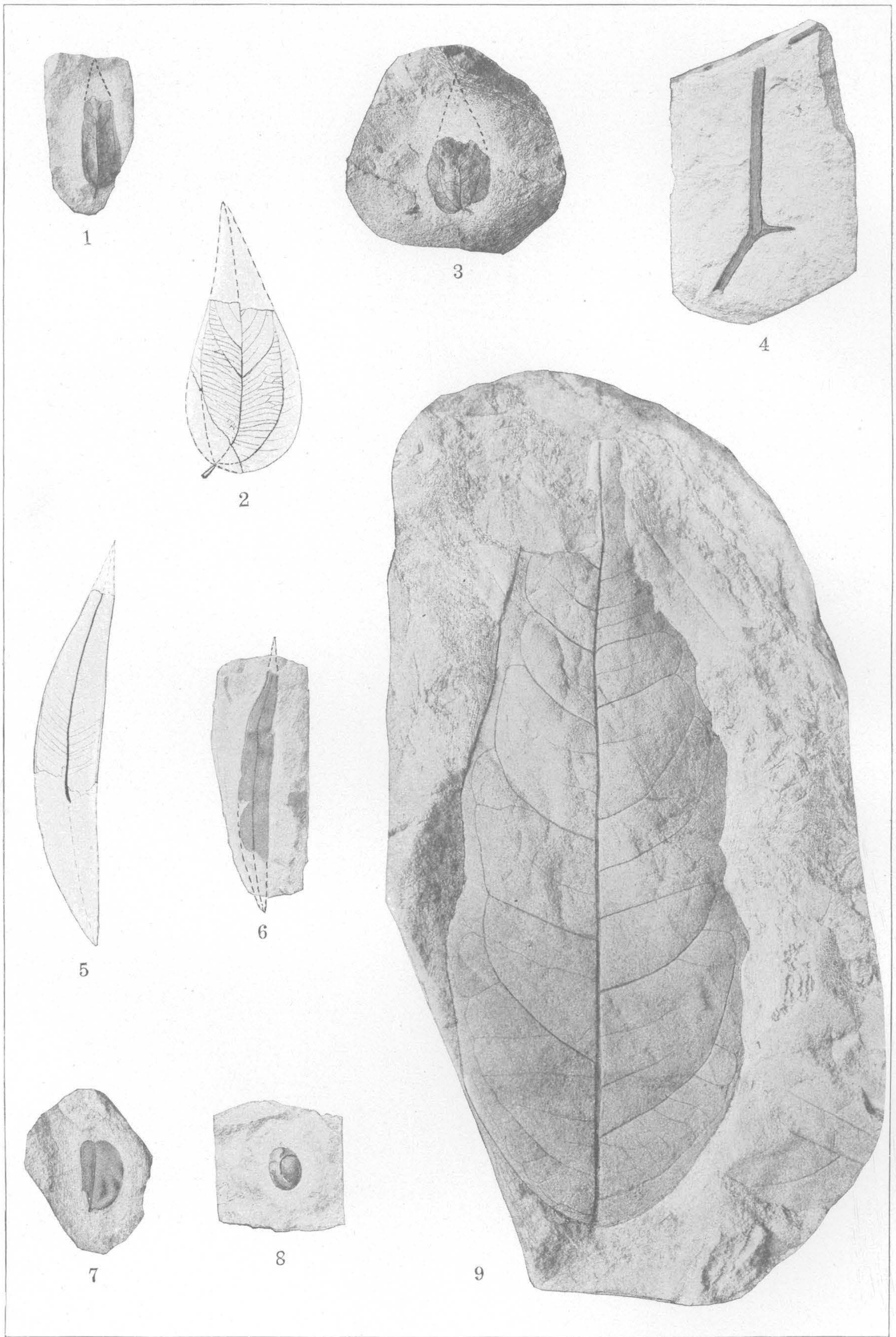
FIGURES 1, 2. *Palmoxylon lacunosum* (Unger) Felix. Near Pollock, La. Figure 1, auxiliary bundle; enlarged 50 times. Its sharp boundary is due to the manner in which the negative has been retouched and is not shown by the material. Figure 2, transverse section of primary bundle; enlarged 50 times. From Catahoula sandstone 236

PLATE LIX.

All from Catahoula sandstone at Chalk Hills, La.



FOSSILS OF THE CATAHOULA SANDSTONE.



FOSSILS OF THE CATAHOULA AND FAYETTE SANDSTONES.

PLATE LX.

MECHANICS OF THE PANAMA CANAL SLIDES.

By George F. Becker.

PREFATORY NOTE.

By George Otis Smith.

This geophysical study of the Panama Canal slides is now presented for the reasons set forth in the following letter of transmittal:

The Director.

Sir:

I have the honor to transmit herewith a paper on the mechanics of the Panama Canal slides. It was prepared as a contribution to the report of the committee of the National Academy of Sciences on the Panama Canal slides, appointed at the instance of the President of the United States.

As some delay is anticipated in completing the full report, this chapter is now submitted for publication with the sanction of President C. R. Van Hise, chairman of the committee.

Very truly, yours,

George F. Becker.

Dr. Becker visited the Canal Zone in 1913 as a geologist of the United States Geological Survey and since that time has given the problem the benefit of his study. His appointment as a member of the committee of the National Academy of Sciences has made it appropriate for his conclusions, based upon his personal observations and already reported in part to the Canal Commission, to be stated for the benefit of his associates and other American scientists and engineers.

OBSERVATIONS ON THE SLIDES.

Early in 1913, before water was admitted, I spent some weeks in examining the geology of the Culebra Cut, now officially known as the Gaillard Cut, with special reference to the origin of the landslides.[1] These appear to me to be of two kinds—mere superficial slips on joint planes or other slippery surfaces and deeper-seated "breaks," as they are known by the engineers. It is only with the latter that this paper is concerned.

The breaks in their inception are marked on comparatively level banks by groups of cracks or narrow fissures nearly parallel to the cut, and these almost immediately develop into series of step faults with small throws, many of them only a fraction of an inch in height, the hade where not vertical being invariably toward the canal so far as I could observe.[2] Many of the steps of these faults are only a yard or two in width. There seems little order in the time of formation of the cracks; in some breaks groups of small faults first appear rather close to the cut, those at a greater distance from it developing later. In others the earliest cracks are hundreds of feet from the canal and the intermediate ground splits up afterward. In all the breaks which I could examine the first small movements involved no perceptible gaping, or none of the same order of magnitude as the throws of the faults. At or about the same time as the cracks on the bank were formed nearly horizontal cracks also appeared in the cut near the bottom of the bank, but which of these were the earlier it seemed impossible to decide.

After a break has made a fair start the cracks more remote from the cut gape and show underlying curved surfaces which reach the general level of the top of the bank nearly at right angles or crop out almost vertically, and at the outcrop the vertical cross section of such a surface shows a very moderate radius of curvature. The surfaces of rupture are fairly smooth, many of them slickenslided a little

[1] I had the great advantage of Mr. Donald MacDonald's companionship throughout these field studies.

[2] Mr. MacDonald records that "some of the blocks sank a little in front and tilted up in the rear, so that they were a yard above the front part of the block behind." This behavior was unusual, and I saw no instances of it. Local inhomogeneities in the bank might perhaps bring about irregularities in surfaces of rupture which would account for exceptional throws of 2 or 3 feet. No other suggestion on this subject occurs to me.

below the outcrop, but not smooth enough to make accurate measurements of their radii of curvature practicable. As nearly as I could discover these radii measured between 100 and 200 feet. Where these underlying surfaces are exposed to a considerable extent it is apparent that the radii of curvature increase rapidly with increasing depth, and some exposures from which disintegrated material had been removed appeared to prove that as the cut is approached the radius of curvature becomes very large indeed.

Movement of the slides perhaps never entirely ceases, but it varies greatly in velocity, from a fraction of an inch a day to many yards. After considerable motion has taken place the sheets of rock are broken up and the external surface of the slide becomes as rough as a choppy sea.

A certain amount of consolidation and of what might be called secondary cohesion sometimes occurs in a slowly moving slide of large dimensions after the material has been reduced to a chaotic condition. In such cases well-developed curved surfaces of rupture and step faults form, indistinguishable in general character from the initial disturbances in the solid bank. This surprising fact indicates that definite mechanical laws of wide applicability underlie the formation of slides. I was witness to these phenomena in the Cucaracha slide, and they have made their appearance in other and more recent breaks.

During the progress of a large slide upheaval of the bottom of the canal may take place from time to time, showing that deformation of the rocks extends to a certain depth below the deepest excavation; but this upheaval does not attend every spasm of activity in the slide, nor does the amount of material thrust up indicate that deformation extends more than a few yards beneath the bottom of the canal. A layer of rock say a hundred feet in width, buckled by nearly horizontal pressure, would show, even if it were only a couple of yards in thickness, mounds of rubble as much as 20 or 30 feet in height, or of the order of magnitude of the observed upthrusts.

LIMITING DEPTH OF DISTURBANCE.

To simplify the mechanical problem as much as possible, suppose the case of a level plain underlain to a great depth by an ideally homogeneous rock. At any depth in this rock the pressure will be hydrostatic and equal to the depth multiplied by the density. Suppose a narrow trench to be sunk vertically in this rock, the width being so small that caving of the sides can be prevented by mine timbering. Then, because of the one-sided relief of pressure there will be at the bottom of the cut a horizontal stress, directed from the wall into the cut, which is equal to the product of the depth and the density. This stress will tend to produce a horizontal shear and to drive the bottom of the wall into the cut. If the cut is sunk deep enough, so deep that the stress is equal to the resistance of the rock to simple shearing stress at the elastic limit, this deformation will occur and the wall will bulge.

This seems a rather hasty statement, but in the last section of this paper the strains are considered in detail; it is there shown that the elastic limit for simple shear would be reached long before the limit for mere linear compression, and that of all elementary resistances that resistance which opposes stress such as is exerted by a pair of scissors is the weakest.

Let the limiting depth at which this one species of flow makes its appearance be denoted by y_1, so that if ρ is the density the hydrostatic pressure is ρy_1, which is also the value of the shearing stress.

CONDITIONS IN A WIDE CUT.

The hypothesis of a narrow timbered cut was employed in finding the limiting depth, y_1, in order to avoid the complication of a caving bank. Let a wide cut be substituted, one a mile wide if the reader chooses, but let the bank be vertical. Then even before the depth y_1 is attained any real rock wall would break down or cave. But imagine for a moment the rock replaced by a substance so tough that, though it would undergo permanent deformation at the same limit as the rock, it would hang on long enough to be studied. A ductile substance, such as wrought iron, would act in this way.

Consider a surface of uniform deformation nearly as deep as y_1 and extending into the wall. This surface will surely not be horizontal, for such a strain would imply the expenditure of an infinite amount of energy.

Before caving can take place in a homogeneous bank the material of the bank must be strained to its elastic limit. The vertical cross section of the bank must therefore include a line along which the strain is uniform. This line must reach the top of the bank somewhere, and it may be assumed that the line is curved, because that is a far more general hypothesis than that it is straight, besides being in harmony with observation.

In fig. 22 OBC represents the bank and ABOD a part of the cut. The x axis, or OX, is taken at a depth y_1 from the original surface, and EC is a curved line along which the shearing stress is uniform. The problem is to find its equation.

At any point the original hydrostatic pressure was $(y_1 - y)\rho$, but excavation of the cut, having disturbed the original equilibrium and brought about strain reaching the elastic limit, has developed a shearing stress which is equal to

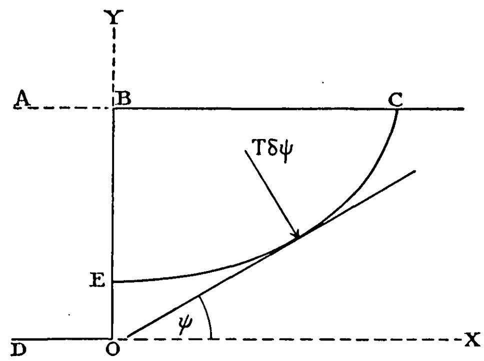


FIGURE 22.—Curve of uniform tangential strain.

$(y_1 - y)\rho$ per unit length and which is of itself inadequate to cause flow. But there is another manifestation of stress to be considered. The shearing stress is equivalent to a tension in the direction of the curve, say T per unit length. Let ψ be the angle which the tangent to the curve makes at xy; let $\delta\psi$ be an elementary angle and δs a corresponding arc. Then elementary mechanics shows that the tension, T, acting along the arc δs is equivalent to a normal pressure [1] $T\delta\psi$.

It has already been explained that ρy_1 per unit length is the shearing stress needful to strain the mass to its elastic limit for simple shear. Hence if stress of this intensity is to be set up along the curve EC the following equation must hold good:

$$T\delta\psi + (y_1 - y)\ \rho\delta s = y_1\ \rho\delta s$$

or, more briefly,

$$\frac{T}{\rho} = y\frac{\delta s}{\delta\psi}$$

[1] See Tait, P. G., Properties of matter, p. 253, 1894; or Lamb, H., Statics, p. 276, 1912.

Here $\delta s/\delta\psi$ is the radius of curvature, say R, while T/ρ is a constant characteristic of the material and essentially positive. It may therefore be replaced by b^2, and then

$$Ry = b^2$$

which is the most general equation of the elastic curve.

Replacing R by its value in terms of dy/dx and d^2y/dx^2 and integrating once gives

$$y^2 = C - 2b^2 \cos\psi \text{..........} (1)$$

where C is a constant of integration. The form of the curve depends on the value of C. For the present problem it is evident that the curve can not cross the x axis and that y can not become negative, so that C must equal or exceed $2b^2$. It is easily proved that if $C = 2b^2$ the equation represents a curve coinciding with the x axis for an infinite distance. This is not a case to be considered, and therefore $C > 2b^2$. The equation then represents the elastic curve of Euler's eighth class, a diagram of which is given in Thomson and Tait's "Natural philosophy," § 611, figure 7.

For some purposes equation (1) is convenient enough. Thus if the ordinate of the point at which the tangent of the curve is vertical is called y_v, then $C = y_v^2$; while if the ordinate at the point where the tangent is horizontal is y_0, then $y_0^2 = y_v^2 - 2b^2$. But values of the abscissae are not so simple.

It is needless to say that the geometry of the elastic curve has been thoroughly known for a century and that this is no place to expound the subject. A few results, however, must be set down. By substituting

$$\psi = 2\varphi - \pi;\ C = 2b^2\left(\frac{2}{k^2} - 1\right)$$

where φ is a variable angle and k is the sine of a constant angle, it will be found that

$$y = \frac{2b}{k}\sqrt{1 - k^2 \sin^2\varphi} \text{..........} (2)$$

Then also

$$dx = \cot\psi dy = \cot 2\varphi dy \text{.......} (2a)$$

and x takes the form of an elliptic integral.

For purely practical reasons (the scope of tables of elliptic integrals) it is convenient to reckon x negatively, or to the left of the origin in figure 23. Then, in the conventional terminology of these integrals,[1]

$$-\frac{x}{b}=\left(\frac{2}{k}-k\right)\Big\{K-F(k,\varphi)\Big\}-\frac{2}{k}\Big\{E-E(k,\varphi)\Big\}\text{--}(3)$$

If, for example, the horizontal distance from the origin to the vertical tangent of the curve is required, $\psi=-\pi/2$ and $\varphi=\pi/4$, and the value of x can be computed from tables of elliptic integrals. Because of symmetry, positive values of x have the same absolute value as negative values.[2]

The element of area of the curve, ydx, is independent of k:

$$ydx=4b^2\ (\sin^2\varphi-\frac{1}{2})\ d\varphi=b^2\cos\psi d\psi$$

so that

$$\int_0^{\psi} ydx=b^2\sin\psi\text{-------------}(4)$$

a result which can be found directly from (1) and (2a).

The length of the curve counted from the horizontal point is given by

$$-\frac{s}{b}=k\{K-F(k,\varphi)\}\text{-----------}(5)$$

and s/b is thus simply proportional to the first part of the value for $-x/b$.

It should be remarked that b^2 is an absolute constant dependent only on the density and tenacity of the rock, so that geometrically b is the unit in which lengths are computed and b^2 the unit area. On the other hand, k varies from curve to curve of a family of curves, all of which share a common value of b, but as k is the sine of an angle it can not exceed unity.

LIMITING VALUES OF k.

It has already been pointed out that if $C=2b^2$ the elastic curve is a horizontal straight line coinciding with the x axis. The same equality implies that k is unity, and therefore, for the problem under discussion, k must always be the sine of an angle less than $\pi/2$. It is equally evident that k can not vanish, for were it to do so the curve would intercept the vertical axis at an infinite distance. There are other reasons for supposing that k can not be very small, and these can be very briefly stated. In this discussion it has not been needful to consider any strains except those at the elastic limit, but the general theory of elastic strains shows that at the edge of a vertical cliff or bank there will be no strain at all, and for some distance from such an edge the strains will be exceedingly small. Hence strains reaching the elastic limit are not to be considered near this edge. It might be possible, but it would not be worth while, to determine how near to this edge the elastic limit could be reached.

On the other hand, it is very important to consider how far back a curve of critical shear can reach, and this I believe to be a simple problem. From the manner in which the equation of the elastic curve was derived it is apparent that the pressure due to tension is a secondary phenomenon due to elastic strain. It is unthinkable that this part of the pressure should exceed the whole pressure requisite to produce flow. But when the curve crops out on the bank at 90° to the horizontal, the pressure due to tension at the outcrop exactly equals the critical tension, $y_1\rho$. Hence for a given value of y_1 the lowest possible curve is that which intersects the level bank at right angles. From this condition the maximum value of k can be determined.

EXAMPLES OF SLIDE CURVES.

In order to illustrate conditions resembling, to a first approximation, those met with in the Culebra Cut, I have computed a few values of the more important elements of the curves, and these are tabulated below. It is easy to see that only relatively large values of $k=\sin\alpha$ are of interest and I have begun with $\alpha=75°$. Taking x_1 as the abscissa of the vertical tangent, it is found from equation (3), while if y_0 is the value of the ordinate for $x=o$, $y_0/b=2\cot\alpha$. Then $y_1^2/b^2=y_0^2/b^2+2$. The fundamental relation $y/b=b/R$ makes it easy to find the radii of curvature answering to x_1y_1 and x_0y_0. For the purpose of the diagram it is not requisite to compute other points; after describing an arc at the axis of symmetry with R_0/b and a second

[1] For the meaning of the symbols in equation (3), see for example Peirce's "Short table of integrals."

[2] Equation (3) is substantially identical with that given by Lamb (Statics, p. 279), who, however, takes the origin at a different point, making x and φ disappear together, so that the y axis includes the maximum value of y. In (3) the origin is so transposed that x and ψ disappear together, so that, as required for the problem in hand, the y axis passes through the minimum value of y, or the point for which $\varphi=\pi/2$.

arc at x_1y_1 with R_1/b, the two can be connected without serious error by the help of a curved ruler.

Points on the elastic curve.

k	x_1/b	y_0/b	y_1/b	R_0/b	R_1/b
sin 75°......	1. 3411	0. 5358	1. 512	1. 866	0. 661
sin 80°......	1. 7094	. 3526	1. 458	2. 836	. 686
sin 85°......	2. 3728	. 1750	1. 425	5. 714	. 702
sin 89°......	3. 9690	. 0350	1. 415	28. 570	. 707
sin 90°......	∞	0	1. 414	∞	. 707

To estimate an appropriate value for b it is requisite to adopt some value for the resistance of the rock either to shearing stress or to crushing. The ultimate resistance to crushing of such materials as soft-burned brick, inferior concrete, and the poorest sandstones is somewhat less than 3,000 pounds per square inch.

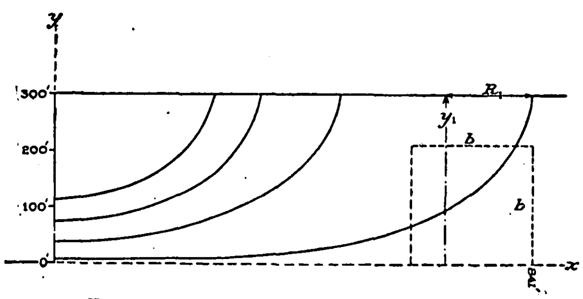


FIGURE 23.—Elastic curve for α=75°, 80°, 85°, 89°.

The Cucaracha formation is probably of similar strength, and I will assume its resistance to be 2,760 pounds. In the concluding section of this paper reasons are given for supposing that $6\sqrt{2}$ times the resistance to shear is about equal to the resistance to crushing, and this implies that for the Cucaracha the resistance to shear is 325 pounds per square inch. This is the weight of a column of rock of a density 2.5 times that of water and 300 feet high.

If the curve for which $\alpha = 89°$ is selected and y_1 is taken as 300 feet,

$$b^2 = \frac{y_1^2}{2(1+2\cot^2\alpha)} = 44{,}972;\ \ b = 212$$

By multiplying all the lengths given in the table by 212 a consistent set of values is obtained.

In the diagram (fig. 23) the height of the bank above the x axis is taken as 300 feet and the curve for $\alpha = 89°$ cuts it perpendicularly at a distance of 841 feet from the y axis. The curves for smaller values of α give larger values for y_1 and therefore cut the 300-foot level at acute angles.

According to the theory here set forth, a limit is set to the vertical height of a cliff or of any rock. Results obtained by the United States Geological Survey indicate that granites show resistances up to 34,000 pounds per square inch, which would correspond to a cliff 3,700 feet high. The brow of El Capitan, in the Yosemite Valley, stands 3,100 feet above the valley, but the top of the dome, some 2,000 feet back from the brow, is about 500 feet higher.

HYDROSTATIC ANALOGY.

If two rectangular blocks of very clean glass are placed in a dish, parallel to one another, and if water is added until the faces of the blocks nearest together are wet to the top in consequence of capillarity, then the vertical cross section of the water surface between the blocks is the elastic curve represented by equations (2) and (3); the height of the blocks above the general water level is given by y_1b, and the amount of water raised above this level by capillarity or surface tension is b^2 per unit length for each wall of the channel between the blocks. If the surface tension is T and the density is ρ then $T/\rho = b^2$.

This system is in stable equilibrium, the surface of the water is minimal for the boundary conditions, and, as the equilibrium is stable, the gravitational potential is a minimum. The whole system may be supposed solidified without disturbance of equilibrium. One-half of this model, to the right or the left of the point at which the capillary curve is lowest, represents the mass beneath a slide on the Culebra Cut. The whole model represents the slide surfaces as they would be were the cut extremely narrow, provided that the material sliding in were removed as fast as it came until the slides "died."

This very perfect analogy and the theory of this paper seem to me to show that the profile of the bed or bottom of a straight watercourse or river, flowing through a homogeneous stretch of country, must tend to approach the elastic curve, and that this profile is also most suitable for a canal.

FORMATION OF RUPTURES.

Thus far the discussion has been limited to conditions appropriate to incipient flow; the rock has been supposed strained to its elastic limit, but short of the point of rupture. In such materials as rocks, which are to be classified as brittle substances, the difference of stress between the so-called limit of solidity and the breaking point is extremely small. Moreover, as a matter of course real rocks are not homogeneous.

Suppose that the limit of solidity has been exceeded by a minute stress increment, but that along some small arc of the elastic curve the rock were more brittle than elsewhere: then evidently a local crack would develop; the resistance along the entire curve would be diminished pro tanto; the stress on the remaining larger portion of the curve would be correspondingly increased; further rupture would follow; and, as it appears to me, the crack would extend from one end of the curve to the other in much less time than is required to state this conclusion. So, on a frozen lake, when a sudden fall of temperature occurs, a crack starts with a report at some point along the shore and tears, booming, across the ice sheet at a velocity approaching that of sound.

If before rupture there is plastic flow along a given curve, then after rupture the overlying mass can move by gravity; for till rupture occurred motion was opposed by cohesion, and when this is overcome resistance is diminished. Thus there is a surplus of energy available to accomplish work.

BULGING OF CANAL BOTTOM.

The necessary and sufficient condition for flow is that $Ry=b^2$, and the smallest value which R can reach is $R_1=b^2/y_1$. The stresses which bring about this condition are due to the tendency of the cliff to settle down into the cut, and this tendency will persist until flow takes place along the basal curve for which $\psi=\pi/2$ at the outcrop.

Strain can not be confined to levels above the bottom of the cut, for the moment the bank begins to sag, even within the elastic limit, adjoining masses are stressed to some extent, and these stresses must extend, with diminished intensity, to great distances. Thus even while the cut is shallow there must be elastic strains along the basal curve. As the depth of the cut increases the strain along this curve must increase until it approaches the elastic limit, both in the wall and below the cut in the plane of the wall.

Now suppose that the cut is nearly but not quite down to the basal curve and that, by some local inequality in the resistance of the material on some part of the basal curve, or in consequence of some jar, due perhaps to movements in the bank, a short local crack forms on some part of the basal curve: then the question arises whether or not this crack will spread. Movement of the mass overlying the curve will be opposed by the horizontal resistance to crushing or buckling of the mass underlying the floor of the cut and extending down to the curve; but when this stratum has been reduced to a very small thickness the crack may extend and cross the vertical, thus splitting off a layer of rock immediately beneath the cut. As has been pointed out above, the formation of a crack along the curve suddenly releases an amount of the energy of position of the bank corresponding to the cohesion which existed until the crack formed and spread. At the expense of this energy buckling or bulging of a thin bottom layer may take place.

This seems to me an adequate qualitative explanation of the upheavals of the floor of the cut observed during the later part of the excavation. That shock had something to do with these upheavals is suggested by the fact that continuous slow upheavals corresponding to the slower movements of the slides were not observed. Upheavals accompanied only the spasmodic accelerations of slide movement. This phenomenon is a harbinger of what would occur if the cut were extended down to the full depth y_1, for then the bottom and sides of the cut would ooze in continuously by plastic flow.

EFFECT OF THE FORM OF THE BANKS.

To simplify discussion it has been assumed that the canal was a vertical cut through a flat country underlain by homogeneous rock, and of course these assumptions are not in accord with the facts. But the country is rather flat; and as the underlying rock is a solid mass, though not a strong one, the variability of load near the surface must be fairly well distributed at depths of more than 100 feet.

Until slides began to give trouble the banks of the cut were very steep—quite too steep, in fact, as everyone would now concede. It is well to consider what would have been the effect of giving the excavation lower slopes.

The ordinary theory of earth pressures on retaining walls is based on the existence of an angle of rest in a pile of discrete particles. It appears to me to be totally inapplicable to conditions in the Cucaracha formation, for the mere existence of breaks demonstrates that the mass possesses continuity. The rocks of the Culebra Cut behave very much as a mass of agar-agar jelly might do if a rectangular mold of this substance, a foot or so in depth, were turned out on a horizontal table. If the jelly were of the right degree of stiffness, the edges of the mass would first sag, and then breaks would make their appearance; but nothing resembling a constant angle of rest would be developed. To work out a complete theory of the relief of pressure in such a jelly, or in the Cucaracha formation, due to an inclination of the walls, would probably be very difficult. Nevertheless, very simple considerations show that sloping the walls is an effectual method of reducing the pressure.

If the Culebra Cut were replaced by an exceedingly strong wall, the pressure against the wall would be hydrostatic. For a small change of depth the increment of pressure would be $\rho(y_1-y)d(y_1-y)$, and the whole horizontal pressure from the surface to depth y_1-y_0 would be $\frac{\rho}{2}(y_1-y_0)^2$.

Now, imagine a plane inclined to the horizon at 45° and passing through the point $x=o,\ y=y_0$. This plane would cut off a triangular slab, say of unit thickness and of mass $w=\frac{1}{2}\rho(y_1-y_0)^2$.

The amount of frictional resistance depends primarily upon normal pressure, so that if F is the frictional resistance and N the normal pressure

$$\frac{F}{N}=\mu=\tan\vartheta$$

where μ is the coefficient of sliding friction and ϑ the angle of friction. Now, F can not exceed the normal pressure N, which excites it, so that μ can not exceed unity and ϑ can not exceed 45°. Hence friction can not prevent movement on a slope of 45°. Thus if the triangular mass of rock (or of jelly) were actually separated from the remainder of the mass, friction would not prevent it slipping down the steep slope. The tangential pressure which the mass w would exert on the 45° plane would be $w/\sqrt{2}$, and this would be resolved into a vertical pressure and a horizontal pressure each equal to $w/2$.

Thus of the whole hydrostatic horizontal thrust exerted against the vertical wall, just one-half is exerted by the triangular slab. Hence also sloping the bank of a cut at 45° would diminish the horizontal thrust to one-half of its maximum value.

It is not difficult to perceive by the further application of elementary statics that the thrust would be still more diminished by making the slope smaller than 45°.

The precaution of giving the banks a low slope might have prevented the occurrence of slides, but as a remedial measure, after breaks have developed to a considerable extent, it seems to me of little avail. After the basal curve has developed into a crack, the material overlying it is either in motion or in unstable equilibrium; and sooner or later all, or nearly all of it, will reach the bottom. Slides of origin similar to those of the Culebra Cut are by no means confined to the Canal Zone. In my opinion banks of cuts should be watched with extreme care, and the moment any cracks make their appearance all other work should be suspended until a safe slope has been established. Breaks should be prevented, because they can not be cured.

NOTE ON FINITE STRAINS.

Plastic flow is continuous deformation without change of density. It takes place at the so-called limit of solidity. During flow, therefore, a solid must be treated as compressed to a constant extent, and as the elasticity of volume is perfect, when stress is relieved the original volume is restored. In nearly all cases a solid mass undergoing flow is to be treated as incompressible.

This limit of solidity depends on the type of strain to which the mass is subjected and to some extent on viscosity. It would also depend on heterotropy, but this paper deals only with isotropic matter.

In any strain ellipsoid there are two symmetrically oriented sets of planes of maximum tangential strain or maximum slide. If the strain is a rotational one (so that the groups of material particles through which the ellipsoidal axes pass vary with the progress of the strain), then there is a difference in behavior of the mass on these two sets of planes. Along that set of geometrical planes which rotates more rapidly through the mass, or on which the material particles change more quickly, greater resistance is offered to flow or rupture than on the other set, because the resistance to be overcome is rigidity plus viscosity and because viscosity offers great resistance to a sudden stress but very small resistance to a stress slowly applied.

In one strain, called simple shear, shearing motion, slide, or scission by various writers, there is one set of these planes which is fixed relatively to the material, while the other set of planes of maximum tangential strain changes its position relatively to the material particles more rapidly than in any other strain.

In scission, therefore, flow will be more easily produced on the fixed set of planes than in a strain of any other type; but on the other set of planes flow will be less easily produced in scission than in a strain of any other type. Scission is due to a couple acting against a resistance. It is the only strain produced in a rod of circular cross section when the rod is twisted about its axis.

Irrotational or pure shear, usually denoted simply as shear, is the simplest conceivable deformation. If a sphere is so distorted that one diameter retains its length unaltered while two other orthogonal diameters, in a plane perpendicular to the first, are so changed that their product is constant, and if all three diameters pass through the same material particles at all stages of the strain, then this strain is a shear, though not a simple shear but yet far simpler than a simple shear. Both strains are illustrated in figure 24.

A pure shear may be conceived as the resultant of two scissions whose rotations are equal and opposite, a fact of which use may be made in the present discussion.

If a cube of homogeneous isotropic matter is subjected to uniformly distributed pressure on two opposite faces, or if the cube rests on a rigid plane and carries a normal load or initial stress, P, then, no matter whether the load and the strain produced are infinitesimal or finite, just one-third of the load is employed in producing cubical compression, the remaining two-thirds being employed in producing two pure shears at right angles to each other.

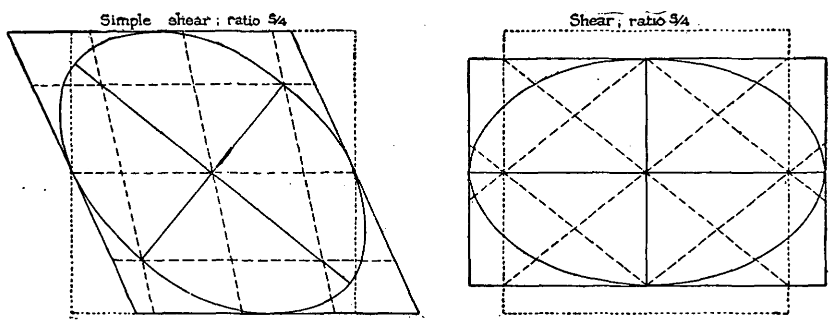


FIGURE 24.—Diagram illustrating simple shear and shear, each of ratio 5/4. The broken lines show directions of maximum tangential strain.

If the strain at the elastic limit is small and if P just exceeds the initial stress needful to produce this strain, the conditions for flow are fulfilled. But to produce yielding relative motion must take place parallel to four planes all of which are at or very close to inclinations of 45° to the direction of the load. Suppose that there were only four planes of relative motion, each passing through two opposite edges of the cube; then if a face of the cube is assumed as the unit area, the area of each of the planes of relative motion will be $\sqrt{2}$, and to produce any yielding by shear the total area of relative motion must be at least $4\sqrt{2}=5.657$.

Now on each of these four surfaces the relative motion may be conceived as due to a scission, the four rotations of the scissions annulling one another by pairs. But if the cube were cut or permanently deformed by scission along a plane parallel to any face the area of deformation would be only unity instead of 5.657.

Call the load or initial stress, P, when just sufficient to induce flow by pure shears K, and let K_s be the tangential stress needful to induce incipient scission. Then it follows from the reasoning stated above that

$$\tfrac{2}{3} K = 4\sqrt{2} K_s, \text{ or } K_s = \frac{K}{8.485}$$

so that if K is known a rational estimate of K_s can be made.

Experimental data as to the relative values of K and K_s for stone, concrete, or brick are not to be had, so far as I know; but for these substances the limit of elastic strain and the breaking point lie very close together. According to Bauschinger the ultimate resistance to shearing of stone is a thirteenth of the resistance to crushing, and this substantially coincides with Von Bach's result for granite. Thus experiment confirms the conclusion that relatively brittle substances will yield to shearing stresses very much less intense than would be needed to produce flow by irrotational strains.

As flow is thus dependent on the type of strain, it follows that flow on one set of planes of maximum tangential strain may be accompanied by no sensible plastic deformation on the opposite set or may there even be attended by rupture.

SUMMARY.

After describing the essential features of the breaks on the Culebra Cut the author points out that there is a limit to the depth of a vertical cut in an homogeneous isotropic mass, the upper surface of which is plane. This limit is that at which the pressure is sufficient to produce simple shear in the mass, and in a concluding note reasons are given for believing that $6\sqrt{2}$ multiplied by the resistance to such shear is about equal to the ultimate strength under linear compression. The depth at which one-sided relief of pressure will produce simple shear is called y_1.

It is shown that in such a bank the profile of a surface along which the mass is strained to the elastic limit must be a form of the elastic curve, the directrix of which lies at a depth y_1.

The lowest or basal slide curve is one which intersects the horizontal bank at right angles. Examples are worked out for this and other cases.

A complete analogy exists between the form of these curves and those which the surface of water assumes when it rises by capillarity between vertical, parallel glass plates.

In view of these results the author discusses to some extent the formation of ruptures, the bulging of the canal bottom, and the effect upon pressure of the form of the banks. A note on finite strains is placed at the end of the paper in order to facilitate skipping.

RELATIONS OF THE EMBAR AND CHUGWATER FORMATIONS IN CENTRAL WYOMING.

By D. Dale Condit.

FIELD DATA.

The information set forth in this paper was obtained in field work during the seasons of 1913 and 1915. During 1913 the writer was engaged in the detailed mapping of the phosphate beds of the Embar formation on the northeast slope of the Wind River Mountains and in the Owl Creek Mountains as far east as Bighorn River canyon. In 1915 the mapping was continued eastward as far as Holt, from which a reconnaissance examination was made east and north along both flanks of the Bighorn Range as far as the latitude of Tensleep. A visit was also made to the west end of the Rattlesnake Mountains and neighboring points in Natrona County, to the Conant Creek anticline, in the eastern part of Fremont County, and to the Sheep Mountain anticline, in the Bighorn Basin.

GENERAL CHARACTER OF THE EMBAR FORMATION.

The term Embar was introduced by Darton[1] to designate strata believed to be of "Permo-Carboniferous" age and lying between the Tensleep sandstone (Pennsylvanian) and the Chugwater formation (red beds of Triassic? age) in the Owl Creek Mountains of Wyoming. The type locality is at Embar post office, about 25 miles west of Thermopolis, where the formation is about 250 feet thick and consists largely of shaly to massive marine limestone, for the most part fossiliferous. Followed laterally eastward, the marine limestones gradually give place to red shales containing many gypsum beds. In the Bighorn Mountains, 70 miles east of the type locality, the transformation of the Embar beds is so complete that they can only with difficulty be distinguished from the overlying red beds composing the Chugwater formation.

The Embar has in recent years attracted attention on account of its yield of petroleum in the Wind River basin and also on account of its phosphate beds, which have been traced and mapped by the United States Geological Survey throughout the Wind River and Owl Creek mountains in the course of land classification. The stratigraphy of the Embar formation as found in the Wind River and Owl Creek mountains has been outlined in a reconnaissance report by Eliot Blackwelder,[2] and those areas will be only briefly reviewed in this paper, the object of which is a consideration of the formation in its eastward extensions from the Owl Creek Mountains into the Bighorn Mountains and from the Wind River range into the Rattlesnake Mountains. (See Pl. LXI.)

As found in typical development, the Embar consists of two principal parts, of which the upper is largely shaly and the lower is chiefly limestone, but includes phosphatic and calcareous shale and nodular chert. The name Park City has been adopted by the United States Geological Survey for the lower part, on the recommendation of Blackwelder, who identifies these beds with the Park City formation of Utah. He has also suggested the name Dinwoody formation for the upper shaly part, from Dinwoody Canyon, in the Wind River Mountains, where the formation, about 200 feet thick, consists of pale-green to white clay and shaly limestone weathering brown and containing obscure pelecypod shells. The Park City and Dinwoody beds as found at these localities are described by Blackwelder in a bulletin on the stratigraphy of the Wind River Mountains, submitted for publication by the United States

[1] Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, p. 35, 1906.

[2] A reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 452-481, 1911.

Geological Survey. The somewhat meager evidence at hand seems to indicate that the Dinwoody beds are of Triassic age and are to be correlated with the Woodside shale and Thaynes limestone of southeastern Idaho. Toward the east the Dinwoody beds thin and change to gypseous greenish or brownish shales devoid of fossils. Outcrops of this character are found in the vicinity of Bighorn River canyon near Thermopolis. Still farther east the beds become increasingly gypseous and assume a lithology that can only with difficulty be distinguished from that of the Chugwater.

There is likewise a gradual transformation in the Park City beds as followed eastward from the Owl Creek and Wind River mountains. These changes may be summarized briefly as follows: (1) Increasing thickness; (2) lithologic changes, including thinning of limestone beds and an increasing amount of shale almost entirely of red color; (3) the appearance of beds of massive white sediment-free gypsum in all but the basal portion; (4) the gradual eastward disappearance of marine fossils except in the basal beds of the formation; (5) the increasing prevalence of calcareous conglomerates at the principal limestone horizons; (6) the disappearance of concentrated beds of phosphate rock. With these changes the equivalents of the Park City and Dinwoody units as found in the Bighorn Mountains so little resemble the typical Embar of the Owl Creek Mountains that the relation would hardly be suspected. The same is true of the Park City beds in the Rattlesnake Mountains as compared with those in the Wind River Range. The one member common to all localities is the nodular chert of the upper part of the Park City beds. It is largely through the persistence of this rock that the relations of the Embar and Chugwater beds have been determined.

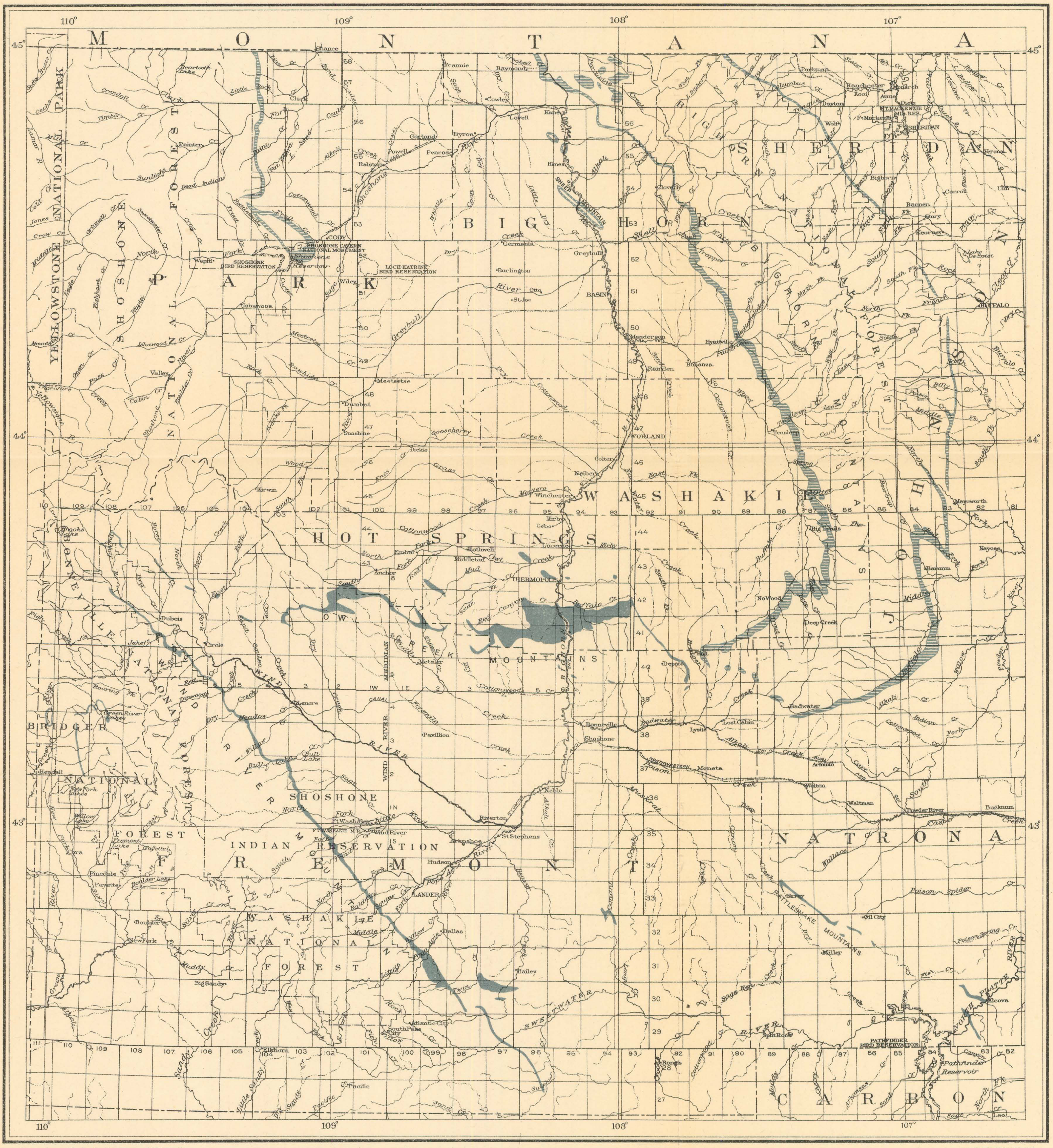
The eastward thinning of the Dinwoody formation and its apparent disappearance at about the head of No Wood Creek, in the southern part of the Bighorn Mountains, may be attributed to nondeposition, although it is possible that the beds have been eroded, or, less probably, that they are present but so closely resemble the Chugwater red beds in lithology as to be unrecognizable.

The character and relations of the Embar and associated strata in the Wind River, Owl Creek, and Bighorn mountains are represented in the accompanying diagram (fig. 26). It is believed that the Embar includes strata ranging in age from Pennsylvanian to Triassic, and that its beds in the Owl Creek Mountains (see Pl. LXII, *A*) grade laterally into beds that were included in the lower part of the Chugwater formation as interpreted by Darton in the Bighorn Mountains. The beds as followed northeast approach the Chugwater more and more closely in lithologic character, and a difficulty arises in determining just how far the name Embar as a formational designation should be carried. Certainly the Embar facies is recognizable for some distance northward into the Bighorn Range, and throughout this part of the field the term Chugwater should be restricted to the overlying red beds, probably of true Triassic age, rather than to all the beds, as the term is applied in the Laramie Range and Black Hills, where strata apparently as old as Pennsylvanian are included.

FACIES OF THE EMBAR FORMATION.

ILLUSTRATIVE SECTIONS.

The lithologic character of the Embar in its typical development in the Wind River and Owl Creek mountains and in its gradual eastward gradation into gypsiferous red beds in the Bighorn Mountain region (Pl. LXII, *B*) is illustrated by the series of sections in figure 25, and also by figure 26, a diagrammatic cross section from the Wind River Range northeastward to the Bighorn Mountains. The first section in figure 25, measured in Bighorn Canyon near Thermopolis, is with slight modifications representative of the marine facies of the Wind River and Owl Creek mountains. The second section was measured near the head of No Wood Creek, T. 41 N., R. 89 W., near the southwest extremity of the Bighorn Mountains. The conditions of deposition here were evidently intermediate between the marine conditions of the west and the shallow-water or lacustrine conditions that prevailed farther east. The third section, measured at the south end of the Sheep Mountain anticline, near Greybull, illustrates conditions not greatly different from those indicated at the No Wood Creek locality. The presence of fossils at several horizons records temporary marine invasions which alternated with partial emergence or shoaling, thus favoring evaporation and concentration into beds of gypsum and possibly



Base from U. S. G. S. map of Wyoming

A. HOEN & CO. BALTIMORE, MD.

MAP OF CENTRAL AND NORTHWESTERN WYOMING

SHOWING OUTCROPS OF EMBAR FORMATION

In the Bighorn Mountains and north of Cody, where the Embar formation is thin or possibly lacking, the outcrop of the Chugwater formation is included

Scale $\frac{1}{1,000,000}$

10 0 10 20 30 40 Miles

10 0 10 20 30 40 50 Kilometers

1916

Embar formation

Embar and Chugwater formations

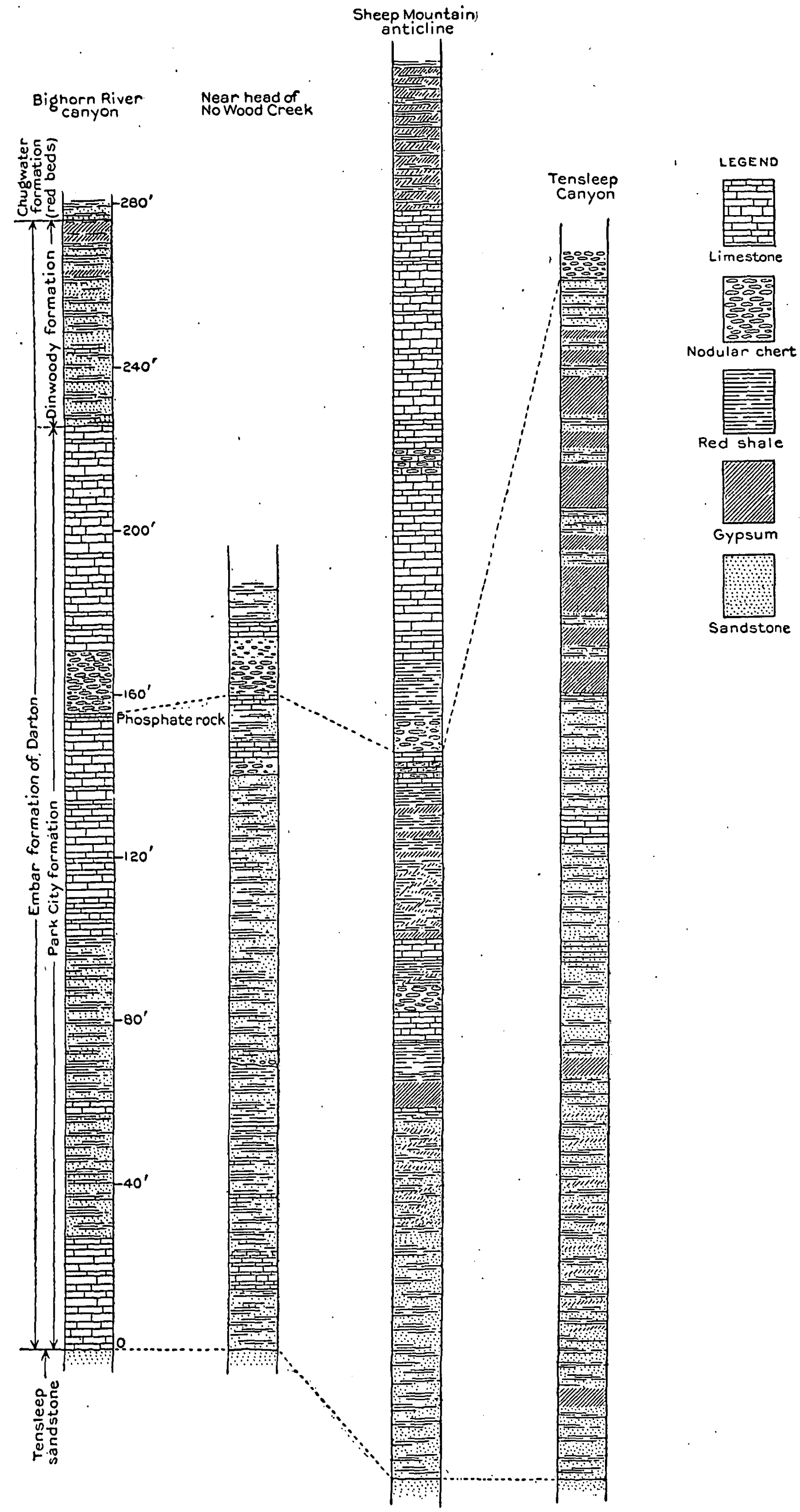


FIGURE 25.—Sections of the Embar formation in central Wyoming.

other salts. The fourth section, measured at Tensleep Canyon, is representative of the formation as found on the west slope of the Bighorn Mountains. Red shales with many thick beds of gypsum and insignificant beds of limestone make up the section. Similar conditions are recorded on the east slope of the same range. The local detailed evidence of the several facies outlined is presented below.

MARINE FACIES OF WIND RIVER AND OWL CREEK MOUNTAINS.

The Park City portion of the Embar formation in the Wind River and Owl Creek mountains consists largely of limestone with calcareous shale and nodular chert. The general sequence, in ascending order, is (1) dolomitic gray fossiliferous limestone, resting with slight unconformity on the Tensleep sandstone; (2) argillaceous shaly limestone and sandy calcareous shale of yellowish color; (3) limestone with geodes, chert masses, and many fossils, among which are *Productus nevadensis*, Leioclema, *Spiriferina pulchra*, and *Productus subhorridus;* (4) phosphatic shale of sepia-brown color, with one or more layers of granular phosphate rock and phosphatic limestone at the base; (5) nodular greenish phosphatic chert interbedded with many shale laminæ; (6) siliceous greenish limestone grading up into gray resistant limestone, with abundant fossils, including Derbya, Pseudomonotis, Leioclema, and *Spiriferina pulchra*. These and other forms mentioned in this paper were identified by G. H. Girty.

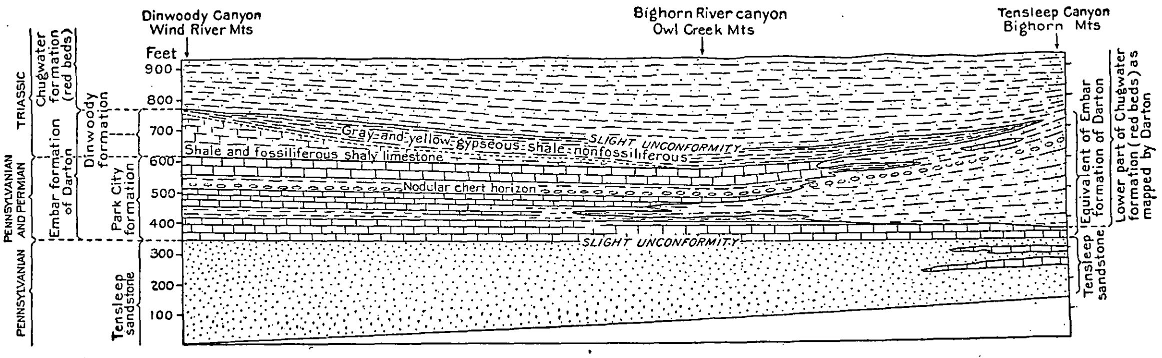
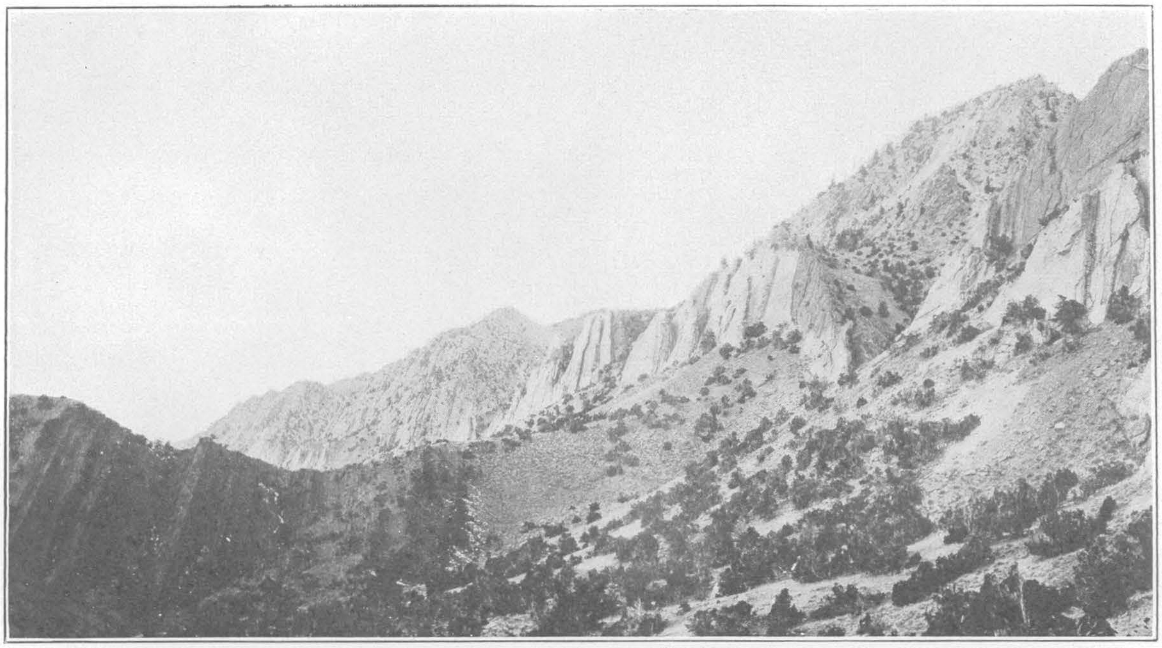


FIGURE 26.—Diagrammatic cross section from Wind River Mountains to Bighorn Mountains, Wyo.

The detailed stratigraphy in the Wind River Mountains is further illustrated by a section measured on South Fork of Little Wind River in T. 1 S., R. 2 W. Wind River meridian. It will be noticed that phosphate occurs at two horizons, one in the upper part and the other near the base. The lower bed is of considerable value in the Wind River Range but is missing in the Owl Creek Mountains.

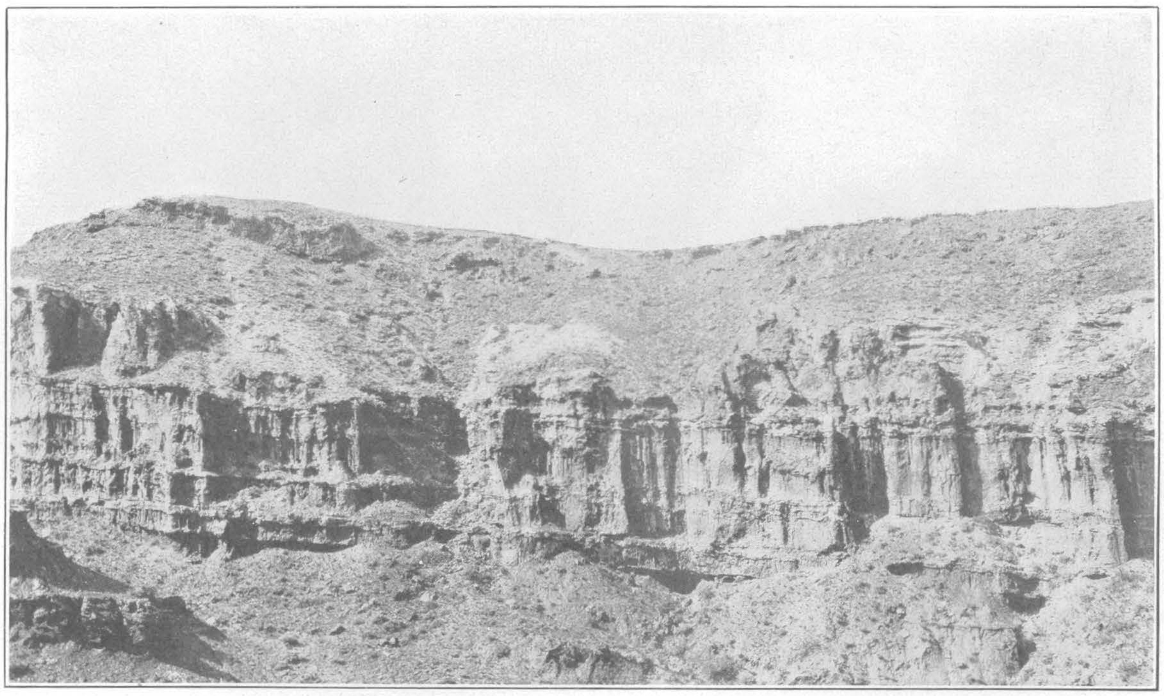
Section of Park City formation on South Fork of Little Wind River, on the northeast slope of the Wind River Mountains.

	Ft.	in.
Limestone, chalky in upper portion, dolomitic and cherty, grayish below	12	0
Limestone, brownish gray, crystalline, fossiliferous; Leioclema, Fenestella, *Spiriferina pulchra*, Derbya, and small crinoid segments plentiful	22	0
Chert, nodular, in bluish-gray shaly matrix	14	0
Shale, siliceous, bluish gray and cherty near top, drab to sepia brown, with phosphate bands, in lower part	37	8
Upper phosphate bed:		
Phosphate, dark, oolitic, sandy; Pugnax only fossil recognized (tricalcium phosphate, 41.14 per cent)	1	4
Phosphate, sandy; *Productus nevadensis* and Pugnax common (tricalcium phosphate, 43.74 per cent)	1	6
Limestone, brownish gray, thin bedded; *Productus nevadensis* and Spirifer aff. *S. cameratus* plentiful. In the lower portion are abundant specimens of Chonetes aff. *C. geinitzianus*	12	0
Limestone, massive, yellowish brown, crystalline; many fossils, Leioclema especially abundant	11	0
Limestone, dolomitic, interbedded with laminated chert and sandy shale	84	0
Limestone, gray, coarsely crystalline, massive; abundant molds of diminutive pelecypods and gastropods	31	0
Lower phosphate bed:		
Limestone, phosphatic, gray, with dark spots; *Lingulidiscina utahensis* present	1	0
Phosphate rock, calcareous, dark, granular (tricalcium phosphate, 36.51 per cent)		6
Limestone, phosphatic, dense textured, dark; a fossil, probably Composita, present		10
Phosphate rock, calcareous; green granules of glauconite (?) abundant; phosphatic shells of Lingulidiscina abound (tricalcium phosphate, 48.13 per cent)	1	0
Phosphate rock, dark, calcareous; few traces of fossils (tricalcium phosphate, 39.92 per cent)		8



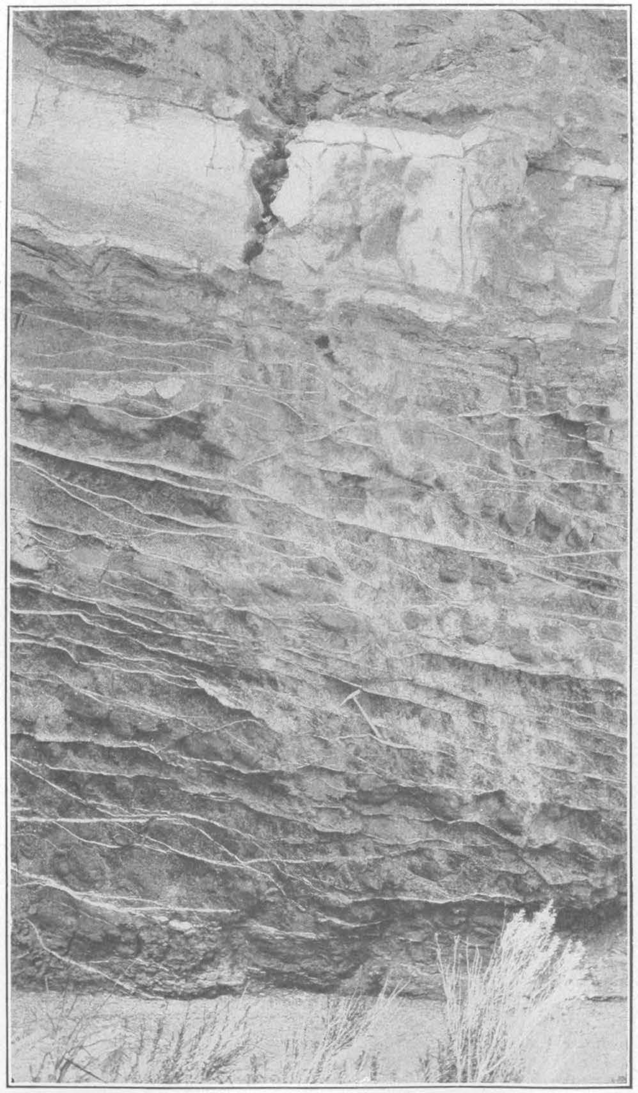
A. EMBAR AND ASSOCIATED FORMATIONS ON SOUTH FLANK OF OWL CREEK MOUNTAINS NEAR SHOT GUN CREEK, WYO., IN T. 7 N., R. 1 E.

Upturned shales of Chugwater formation at left; resistant upturned limestone of Park City formation at right, underlain by Tensleep sandstone, which forms the highest hill in the foreground at right.



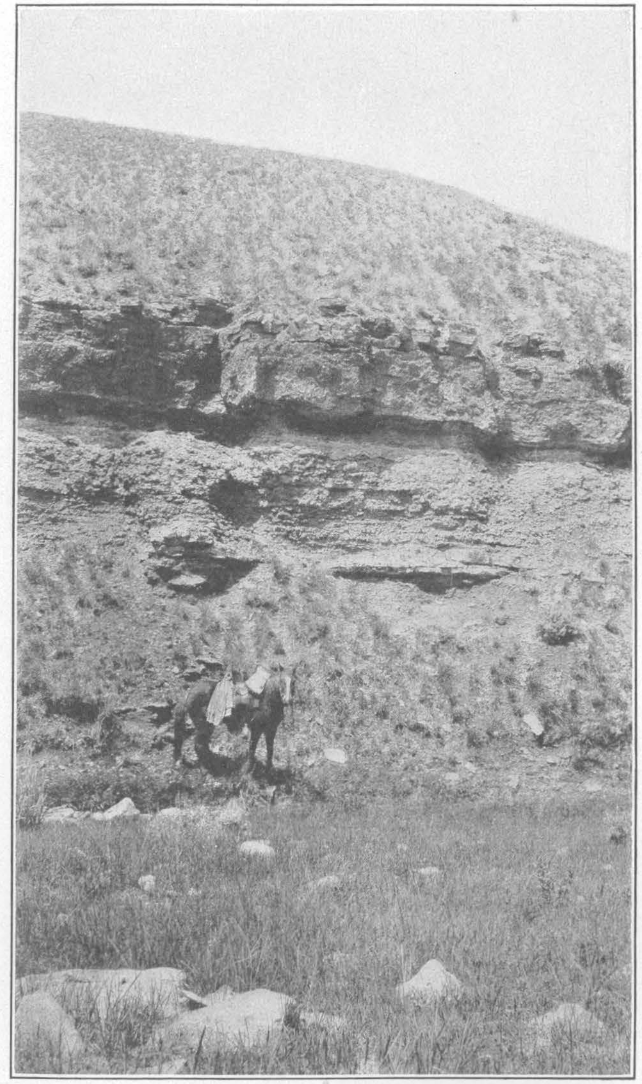
B. RED BEDS IN MIDDLE OF EMBAR FORMATION ON EAST SLOPE OF BIGHORN MOUNTAINS NEAR BARNUM, WYO., IN T. 42 N., R. 84 W.

At top of hill is calcareous conglomerate. The beds below consist of structureless friable sandy red shale with irregular laminæ of limestone, much distorted and faulted. These beds rest on even, undisturbed layers of limestone that form the basal part of the Embar formation. Thickness to top of hill is about 90 feet.



A. BED AND VEINLETS OF GYPSUM IN LOWER PART OF EMBAR FORMATION NEAR SOUTH END OF SHEEP MOUNTAIN ANTICLINE, WYOMING.

About 17 feet above the 4-foot layer of gypsum is limestone filled with marine fossils. The veinlets of gypsum are in structureless red shale.



B. NODULAR CHERTY SHALES OVERLAIN BY LIMESTONE IN UPPER PART OF EMBAR FORMATION NEAR HEAD OF NO WOOD CREEK, WYO., IN T. 41 N., R. 89 W.

At the base is phosphatic limestone in the geologic position of the principal phosphate bed found elsewhere.

	Ft.	in.
Limestone, granular, thick bedded, having small calcite vugs; granules of glauconite (?) present.	12	0
Limestone and dolomite, argillaceous, gray, with cherty layers and localized green stains	31	0
Chert, white and gray, laminated	7	0
Limestone, buff, dolomitic, resting on Tensleep sandstone	4	0

At certain points along the Wind River Mountain front the limestone beneath the lower phosphate bed is rich in cephalopod and gastropod forms believed by Mr. Girty to indicate Pennsylvanian age. The upper phosphate bed contains the *Spiriferina pulchra* fauna, which is regarded as of Permian age.

TRANSITIONAL FACIES.

The exposures at the Sheep Mountain anticline and near the head of No Wood Creek illustrate conditions intermediate between the marine facies of the west and the shallow-water, arid conditions of the east.

In the Sheep Mountain region the fossiliferous limestones of the upper two-thirds of the formation show that deposition for the most part took place in sea water. A little below the middle, however, persistent beds of gypsum (Pl. LXIII, *A*) alternate with the fossiliferous limestones, indicating intermittent restrictions of the sea and concentration of the water, which temporarily favored precipitation. The fine-textured arenaceous even-bedded red shales of the lower part denote deposition for the most part at or a little below sea level. The general absence of coarse sandy sediments here and elsewhere at the Park City horizon indicates that the land areas supplying the sediments were reduced nearly to base-level and that the products of erosion were carried by streams of low gradient. The source of the sediment is a matter of speculation but may have been land to the east, for the beds thicken in that direction.

Evidence of depositional conditions equivalent to those recorded near Greybull and at the head of No Wood Creek is found at the west end of the Rattlesnake Range, in Natrona County. The Park City beds, where observed near the Jamison ranch, in T. 33 N., R. 88 W., are about 300 feet thick and consist largely of red shales with a few impure limestone beds and one limestone member about 25 feet thick near the base. The upper part of the formation contains much reddish-brown nodular chert (Pl. LXIII, *B*), with which are associated Derbya and other fossils characteristic of the upper part of the Park City formation. No gypsum beds were discovered here, but some have been noted by C. J. Hares at Alcova, about 35 miles to the southeast.

SHALLOW-WATER FACIES.

Arid conditions, favoring concentration of brines and deposition of thick beds of gypsum and probably other salts, prevailed in the Bighorn Mountain region almost from the beginning of Embar time. The basal 20 feet or so of strata resting on the nearly even upper surface of the Tensleep sandstone consist of dolomitic cherty limestones with a few marine fossils, overlain by green and red shales containing locally a layer of impure fine-textured curly brown limestone, apparently of algal origin. Higher strata have little regularity of sequence, but there is a predominance of arenaceous red beds which are gypseous throughout and contain an increasing amount of gypsum toward the top. The thickest gypsum beds in the upper part of the formation are locally 100 feet or more thick and consist of numerous clean white layers 5 to 10 feet thick, lacking mechanical sediments and alternating with thin layers of red shale and laminæ of dolomitic limestone, generally a few inches thick. In the upper part of the formation there is a persistent layer of nodular purplish-red chert in the midst of the gypseous beds. The chert bed has been traced continuously eastward from the Owl Creek Mountains and is believed to lie at the same horizon as the greenish chert above the phosphate bed of that region.

The gypsum beds are prominent at Tensleep Canyon, at Cherry Creek near Redbank, and at numerous other points on the west slope of the Bighorn Mountains, being 50 to 100 feet or more in thickness at a number of places. Deposits even thicker than this are found on the east slope of the mountains, along the several forks of Crazy Woman Creek, and to the south, along branches of Powder River.

One of the noteworthy features concerning the gypsum beds is that they are not persistent. They grade laterally into red beds and conglomeratic limestone of vesicular, tufaceous texture. The gypsum and conglomerate beds lie approximately at the same horizon and are found in the same general vicinity, but are not as a rule associated in any one section. The gradation from one to the other not uncommonly takes place within a distance of a few hundred yards. This mode of occurrence is in large part a result of the conditions of deposition, which favored prolonged evaporation in numerous small basins, the margins of which were above water from time to time, permitting a drying and cracking of the calcareous muds and slight erosion. The fragments were rolled along and cemented by calcareous deposits of tufaceous character. The conglomerate pebbles, consisting of red shale, friable sandy material, limestone, and chert, all of local origin, occur at several horizons. A peculiar result of weathering of this rock is the removal, partly by solution and partly by wind erosion, of many of the pebbles, leaving the calcareous matrix of vesicular texture with rounded cavities as much as 4 to 6 inches in diameter.

The nonpersistence of the gypsum beds is in part attributed to solution in recent times. Evidence supporting this conclusion is seen along the east slope, where sink holes are not uncommon, and also in the absence of gypsum in exposures extending a short distance up the mountain slope. This feature is especially noticeable near No Wood and Redbank, where there is an abundance of bedded gypsum up to about the 6,700-foot contour and none at all in higher exposures. Stratigraphic measurements above and below this elevation show a corresponding difference in thickness.

The irregularity of the gypsum beds is also in part attributable to partial solution at different times in the past, when it has been favored by the ever-changing ground-water conditions. The chief evidence of this process is the greatly distorted character of the rocks in all but the basal part of the formation. The distortion is noticed even in exposures along the base of the mountains. The arenaceous red clays are structureless and loosely cemented. Thin laminæ of limestone distributed through the section are faulted and tilted in edgewise blocks. The evident disturbance of these beds and the undisturbed character of the underlying beds indicate that there has been a widespread collapse through the removal of soluble parts of the beds, perhaps at different times. Possibly the soluble parts included salt as well as gypsum. In fact, the data would seem to indicate that they did, because a certain amount of distortion is noticed even in exposures where there is much gypsum. The possibility of the former presence of saline deposits leads to the query whether those salts may not still exist down the dip far below the surface.

The evidence at hand seems to indicate that the gypsum beds were deposited under conditions somewhat different from those prevailing during the deposition of the gypsum beds found in the upper part of the Chugwater, which are described by Branson.[1] The red beds (Chugwater), which are coextensive with the Embar in Wyoming and range from about 1,000 to 1,400 feet in thickness, are believed by Branson to be for the most part of marine origin, and the presence of the gypsum in the upper part is regarded as pointing to marine origin for that part of the red beds in most of Wyoming. The reasons for his conclusions are set forth as follows:

1. Uniformity in thickness of beds over wide areas.
2. Uniformity in texture of rocks over wide areas.
3. Ripple marking on horizontal beds through most of the formation.
4. Chemical precipitation of limestone at the 800-foot level.
5. Chemical precipitate of gypsum near the top over wide areas and at various levels in many places.
6. Absence of sun cracks and fossils of land animals excepting in the Popo Agie beds.
7. Presence of undoubted subaerial evidences in the Popo Agie beds, with textures and materials like much of the rest of the red beds.

The succession of events is summarized as follows:

1. The red beds began under marine conditions, and the sea gradually became more and more charged with calcium carbonate and magnesium carbonate until a dolomitic limestone was precipitated.
2. Above the limestone the sea gradually filled with sand until the sediments were exposed, and the Popo Agie beds were formed under subaerial conditions.
3. The sea in upper Triassic time readvanced and some 200 feet of sandstone and shales filled the western margin.
4. Subaerial deposition, mainly of wind-blown sand, succeeded and lasted while beds varying from a few feet to 60 feet in thickness were deposited.
5. The sea readvanced, but concentration of calcium sulphate had been in progress for a long time and soon resulted in widespread deposits of gypsum.
6. Usually some sandstone and some thin layers of limestone were deposited above the gypsum before the withdrawal of the sea at the close of the period.

[1] Branson, E. B., Origin of the Red Beds of western Wyoming; Origin of thick gypsum and salt deposits: Geol. Soc. America Bull., vol. 26, No. 2, pp. 217-242, 1915.

Darton's conception of the history of Chugwater red-bed deposition is as follows:[1]

In the latter part of Carboniferous [Pennsylvanian] time, and probably during the Permian also, there was a widespread emergence, resulting in shallow basins with very wide mud flats which occupied a large portion of the Rocky Mountain province. In these regions were laid down the last deposits of the Pennsylvanian division and the great mass of red clay and sands constituting the Chugwater formation. These beds probably were deposited by saline water under arid-climate conditions and accumulated in a thickness of 1,000 feet or more. The waters were shallow much of the time, and there were wide, bare wash slopes and mud flats, as is indicated by the frequent mud cracks, ripple marks, and impressions of various kinds on many of the layers throughout the formation.

In contrasting the Embar of the Bighorn Mountains with the overlying Chugwater beds the following features are noted:

1. Limestone is much more plentiful in the Embar, but, aside from that which occurs in the basal portion, it is in small patches laterally alternating with thick beds of gypsum.

2. There is ample evidence of frequent emergence and slight erosion during late Embar time, a feature not observed in the Chugwater. This is especially true of exposures on the east slope of the Bighorn Range. The conglomerates are, in part, composed of travel-rounded pebbles, denoting contemporaneous erosion. There are, however, other conglomeratic beds regarded as breccias. These consist of angular pebbles of various materials bound together by a spongy calcareous, travertine-like cement. The brecciated portion may be in part of secondary origin, produced by the solution of gypsum and possibly salt beds and the resultant collapse of the strata. Breccias and conglomerates such as these have not been observed in any part of the Chugwater formation.

3. Although the evidence of contemporaneous erosion in the Embar denotes temporary emergence, it is believed that the materials were for the most part laid down beneath the surface of the sea. The persistence of the nodular chert and the similarity of certain other beds over nearly all the area indicate that throughout Embar time the sea waters frequently extended from the west over the entire region. Reductions of the sea were the rule during the later part of the epoch, and aridity favored prolonged evaporation of the inclosed salt-water basins.

[1] Darton, N. H., Paleozoic and Mesozoic of central Wyoming: Geol. Soc. America, Bull., vol. 19, pp. 465–466, 1908.

SOURCE OF MATERIALS.

The source of the materials of the Tensleep, Embar, and Chugwater formations is largely a matter of speculation. That the Tensleep sandstone was at least in part deposited in the sea is indicated by its beds of arenaceous dolomite, some of which contain fossils. The following collection was obtained from beds a little above the middle of the formation on the east slope of the Bighorn Range in T. 44 N., R. 84 W.:

Crinoid stems.
Nucula levatiformis var. obliqua.
Deltopecten sp.
Astartella subquadrata?
Schizodus ovatus.
Plagioglypta canna?
Lævidentalium? sp.
Bellerophon aff. B. sublevis.
Euphemus? sp.
Bucanopsis? sp.
Phanerotrema aff. P. grayvillense.

Mr. Girty reports that the fauna is too small to warrant positive statement as to its relations. It shows a new and very indefinite combination of specimens, which may be late Pennsylvanian or, less probably, Permian. Elsewhere reedlike, columnar plant remains have been observed in the Tensleep sandstone.

It has been found that over the greater part of central Wyoming there is a general southward direction of inclination of the lines of deposition, suggesting a possible derivation of the sands from the north; but this view is not supported by the data as to thickness, for the formation at the north end of the Bighorn Range is 30 to 40 feet thick and increases southward to 200 or 300 feet in the Owl Creek Range and to more than 500 feet in the Wind River Range.

The slight thickening of the Embar formation eastward from Bighorn River canyon into the Bighorn Mountains has been mentioned. There is likewise a gradual increase to the southwest, where the beds become more and more calcareous. The change is not considerable westward along the Wind River Mountain front, and, in fact, the formation thins from about 430 feet at Dinwoody Canyon to a little more than 200 feet about 50 miles farther northwest, across the divide, on Buffalo Fork of Snake River at a locality measured by Blackwelder.

ABSTRACT OF PAPER.

The Embar formation of central Wyoming, which lies between the Tensleep sandstone and the Chugwater formation, comprises several distinct facies, each of which is considered in detail, and some of the formational boundaries in the Bighorn Mountain region are redefined. In connection with the description of the gypsum and associated strata it is suggested that conditions were possibly also favorable for accumulation of salt beds. The chance of finding such deposits down the dip below the surface is believed to be sufficient to merit further investigation.

CONTRIBUTIONS TO THE GEOLOGY AND PALEONTOLOGY OF SAN JUAN COUNTY, NEW MEXICO.

1. STRATIGRAPHY OF A PART OF THE CHACO RIVER VALLEY.

By Clyde Max Bauer.

INTRODUCTION.

This preliminary paper is an attempt to set forth the principal features of the stratigraphy in a part of the San Juan Basin—to describe the succession of strata irrespective of possible correlations and thereby to establish a type section for the formations exposed and to bring out their relations to the strata immediately above and below. The paper presents only a part of the data collected by a field party of the United States Geological Survey in the season of 1915, in charge of the writer, and does not describe the economic resources of the area, such as coal, nor the general geologic problems.

In mapping formation boundaries, streams, roads, and other surface features, the plane table and alidade were used. Where the slopes are steep and the strata nearly horizontal, sections were measured directly with a hand level. Elsewhere the alidade was employed for obtaining distances and differences in elevation, and the thickness of the intervening strata was calculated from these data. Fossils were collected at localities whose positions were accurately determined, both stratigraphically and geographically.

The accompanying papers on the paleontology of the area, by C. W. Gilmore, T. W. Stanton, and F. H. Knowlton,[1] discuss the fossil collections made by the field party. For these collections and a considerable part of the other data, including mapping, much credit is due to John B. Reeside, jr., who assisted the writer both in the field and in the office, and to H. R. Bennett, who assisted in the field. Acknowledgments are also due to M. R. Campbell, who exercised general supervision over the work and made many helpful suggestions and criticisms.

GEOGRAPHY.

The area studied and mapped comprises about 1,500 square miles in northwestern New Mexico extending along Chaco River for about 50 miles from the Great Hogback, on San Juan River, to Meyers Creek, 6 miles north of Pueblo Bonito. (See Pl. LXIV.) The area may be reached by the Denver & Rio Grande Railroad, a branch of which terminates at Farmington, on the northern edge, or by the Santa Fe Railway to Thoreau, which lies about 60 miles south of Meyers Creek. From Thoreau wagon roads lead northward and cross the Continental Divide at San Antonio and Sheep passes. The population of the area, which lies partly in the Navajo Indian Reservation, is composed largely of Navajo Indians, who raise sheep, goats, and ponies and are nomadic in their habits. Sagebrush, rubber weed, chico, and pear cactus are the most common plants of the desert plain. A few white traders have located stores (see Pl. LXVIII, *B*) in the area.

The region is arid and stands from 5,200 to about 6,500 feet above sea level. The drainage goes mainly westward through arroyos cut sharply into the westward-sloping plain (see Pls. LXVI, *C*, and LXXI, *B*) to Chaco River. Between the arroyos are broad, gently rolling interstream plains, most of them surmounted by numerous long dunes of windblown sand and offering few exposures of the stratified rocks. The arroyos, on the other

[1] U. S. Geol. Survey Prof. Paper 98, pp. 279-353, 1916 (Prof. Papers 98-Q, 98-R, 98-S).

hand, present excellent exposures of the strata, especially near their heads, where there are many areas of badlands (see Pls. LXVIII, *A*, and LXXI, *B*), in which vegetation and soil are lacking and the rocks can be studied in great detail. These badland areas are cut below the general level and most of them are therefore invisible from the upland, except near their edges.

San Juan River is the only permanent stream in the area. It is maintained to a large extent by the melting snows on the mountains at its source, and, although the water is muddy, it contains far less alkali than the water of the other streams of the region. Chaco River has a bed as wide as that of San Juan River, but, although it is over 150 miles long, water flows in the channel only at intervals and only for a few days at a time. Its bed during the remainder of the year is a barren sandy flat. The water supply for the area is therefore obtained almost entirely from wells and artificial lakes. The rain water, caught in artificial lakes or pools, is carefully conserved through the long, dry periods. The water from the wells is strongly alkaline and commonly salty, and in many places it is not fit for domestic use. However, through long experience, the Navajo Indians have sought out the best watering places and have sunk crude wells and constructed reservoirs for storing flood waters.

STRATIGRAPHY.

GENERAL FEATURES.

The name San Juan Basin has been used by several writers to refer to the area inclosed by the outcrop of the Cretaceous coal-bearing formations of northwestern New Mexico. This area is properly a structural basin, and the writer would therefore limit the term to the region in which the strata dip toward a common center and exclude the Zuni Basin on the south, which is separated from the main basin by a structural divide.[1] The stratigraphy of the west-central part of the San Juan Basin is described in this paper. The area includes the outcrop of strata overlying the Mesaverde formation, which have in the past been referred to the Lewis, Laramie, Puerco, Torrejon, and Wasatch formations.

The stratified rocks of this area consist of a succession of marine, brackish-water, and fresh-water sediments, which now occur as sandstone, shale, coal, and conglomerate, in almost every gradation and combination possible. The dip of the strata throughout the greater part of the area is from 1° to 3° toward the center of the basin. In the Great Hogback, however, the beds lie in a sharp monocline dipping as much as 47° in an easterly direction. This steep dip persists only a short distance, however, and beyond it the beds flatten to dips of 3° or less.

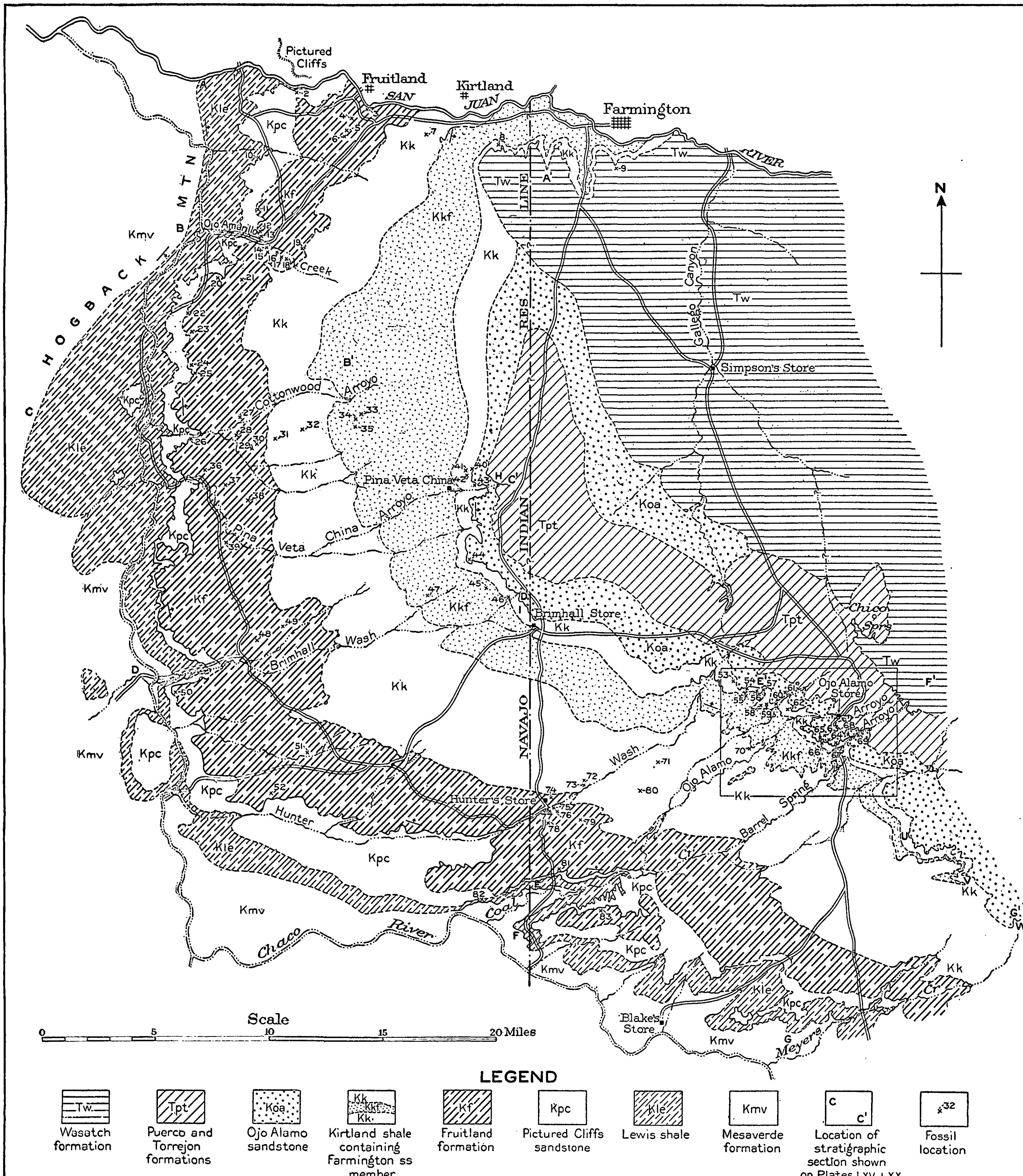
The sections given in Plate LXV show the thickness and character of the units measured along several arroyos, as shown on the map (Pl. LXIV). The area was entered from the north, and the first section was measured along San Juan River. (See A–A′, Pl. LXIV.) A generalized profile of this section is also shown in figure 27 (p. 275). Here the exposures are good, permitting a division into mappable units on a basis of lithologic differences. The Mesaverde and Lewis formations and the Pictured Cliffs sandstone were accepted as described by previous workers in the San Juan Basin,[2] as the two former have been traced directly from their type localities and the San Juan River valley is the type locality for the Pictured Cliffs sandstone.[3] The beds above this sandstone were divided into mappable lithologic units. As the present work progressed southward the distinctness of these units became more and more evident, and the sections measured were easily correlated with that along the river.

The following table gives the names and thicknesses of the several formations described in these pages, as well as the names previously used for them:

[1] Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 376–426, 1907.

[2] Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 285, pp. 241–258, 1906. Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 376–426, 1907.

[3] Holmes, W. H., Geology of the San Juan district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1875, p. 248, 1877.



GEOLOGIC MAP OF WEST-CENTRAL PART OF THE SAN JUAN BASIN, N. MEX., FROM THE GREAT HOGBACK TO MEYERS CREEK.

The rectangle indicates the area shown on Plate LXIX.

Geologic formations in the west-central part of the San Juan Basin, N. Mex.

Holmes, 1877.[a]	Shaler, 1907.[b]	Gardner, 1909.[c]	Sinclair and Granger, 1914.[d]	This paper.	
				Formation.	Thickness (feet).
Wasatch.	(Undifferentiated Tertiary.)	Wasatch.	Wasatch.	Wasatch formation.	500+
[Absent in area described.]		Torrejon.	Torrejon.	Torrejon and Puerco formations.	390
		Puerco.	Puerco.		
Laramie.	Laramie.	......(?)......	Ojo Alamo.	Ojo Alamo sandstone.	63–110
		Laramie.	........(?)........	Kirtland shale, including Farmington sandstone member.	836–1,180 0–455
				Fruitland formation.	194–292
Pictured Cliffs.			[Not described.]	Pictured Cliffs sandstone.	49–275
Sand shale group.	Lewis.	Lewis.		Lewis shale.	76–475
Mesa Verde.	Mesaverde.	Mesaverde.		Mesaverde formation.	1,980

[a] Holmes, W. H., Geology of the San Juan district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1875, p. 244, 1877.
[b] Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, p. 376, 1907.
[c] Gardner, J. H., The coal field between Gallina and Raton Spring, N. Mex., in the San Juan coal region: U. S. Geol. Survey Bull. 341, p. 338, 1909.
[d] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297–316, 1914.

MESAVERDE FORMATION.

The Mesaverde, which is the lowest formation examined in this area, exhibits the same characteristics here as in the type locality, the Mesa Verde National Park, except that it is somewhat thicker. Where the Great Hogback is cut by Chaco River the thickness of the Mesaverde is 1,980 feet. At this place it presents a striking monocline with an eastward dip of 35°–47°. The formation is composed here of a lower sandstone member, which contains coal in its upper part; a middle shaly member, which comprises thin-bedded sandstone, shale, and coal; and an upper massive sandstone member. This formation was not studied in detail and only its upper limit was mapped.

LEWIS SHALE.

The Lewis shale (see Pl. LXVI, *B*) is marine in origin and very similar to the shale at Fort Lewis, Colo., the type locality.[1] It is thinner here, however, than at Fort Lewis, being about 475 feet thick on San Juan River, decreasing gradually southward as far as Coal Creek, where it is 76 feet thick, and increasing again to 103 feet on Meyers Creek. (See Pl. LXV.) The Lewis shale exhibits the same lithologic characteristics throughout the field. It is a greenish-gray sandy shale with local streaks of yellowish calcareous shale. On San Juan River it has also a prominent layer of buff lime concretions about 100 feet above its base. Three collections of fossils were obtained from it and have been identified by T. W. Stanton. They are listed below. (See also Pl. LXV.)

Collection 1 (9277):
- Anomia sp.
- Inoceramus? sp.
- Lucina sp.
- Lunatia sp.
- Baculites sp.
  - Marine Montana fauna.

Collection 10 (9273):
- Inoceramus barabini Morton.
- Placenticeras intercalare Meek and Hayden.
- Undetermined burrows.

[1] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899.

Collection 82 (9296):
- Ostrea inornata Meek and Hayden.
- Syncyclonema sp.
- Leda sp.
- Cardium speciosum Meek and Hayden.
- Liopistha undata Meek and Hayden.
- Lunatia sp.
- Placenticeras sp.

Marine Montana fauna.

PICTURED CLIFFS SANDSTONE.

Overlying the Lewis shale conformably is the Pictured Cliffs sandstone (see Pl. LXVII, *A*) of near-shore marine origin. Its contact with the Lewis is gradational, but in the aggregate its lithology is distinct from that of the beds beneath. As the name indicates, it is a sandstone that forms cliffs, particularly on San Juan River immediately west of Fruitland, where there are prominent cliffs of copper-colored sandstone 20 to 40 feet high. Farther south it is a yellowish to light-gray or brown sandstone and not so massive. It diminishes in thickness from 245 feet on San Juan River to 49 feet on Brimhall Wash, and from that place increases to 91 feet on Meyers Creek. (See Pl. LXV.) *Halymenites major* is abundant in this formation, and the following fossils, identified by T. W. Stanton, were also collected from it:

Collection 2 (9278):
- Serpula sp.
- Inoceramus barabini Morton.
- Cardium speciosum Meek and Hayden.
- Tellina scitula Meek and Hayden?.
- Leptosolen? sp.
- Mactra gracilis Meek and Hayden?.
- Corbula sp.
- Turris? sp.
- Odontobasis? sp.
- Haminea sp.
- Actæon sp.

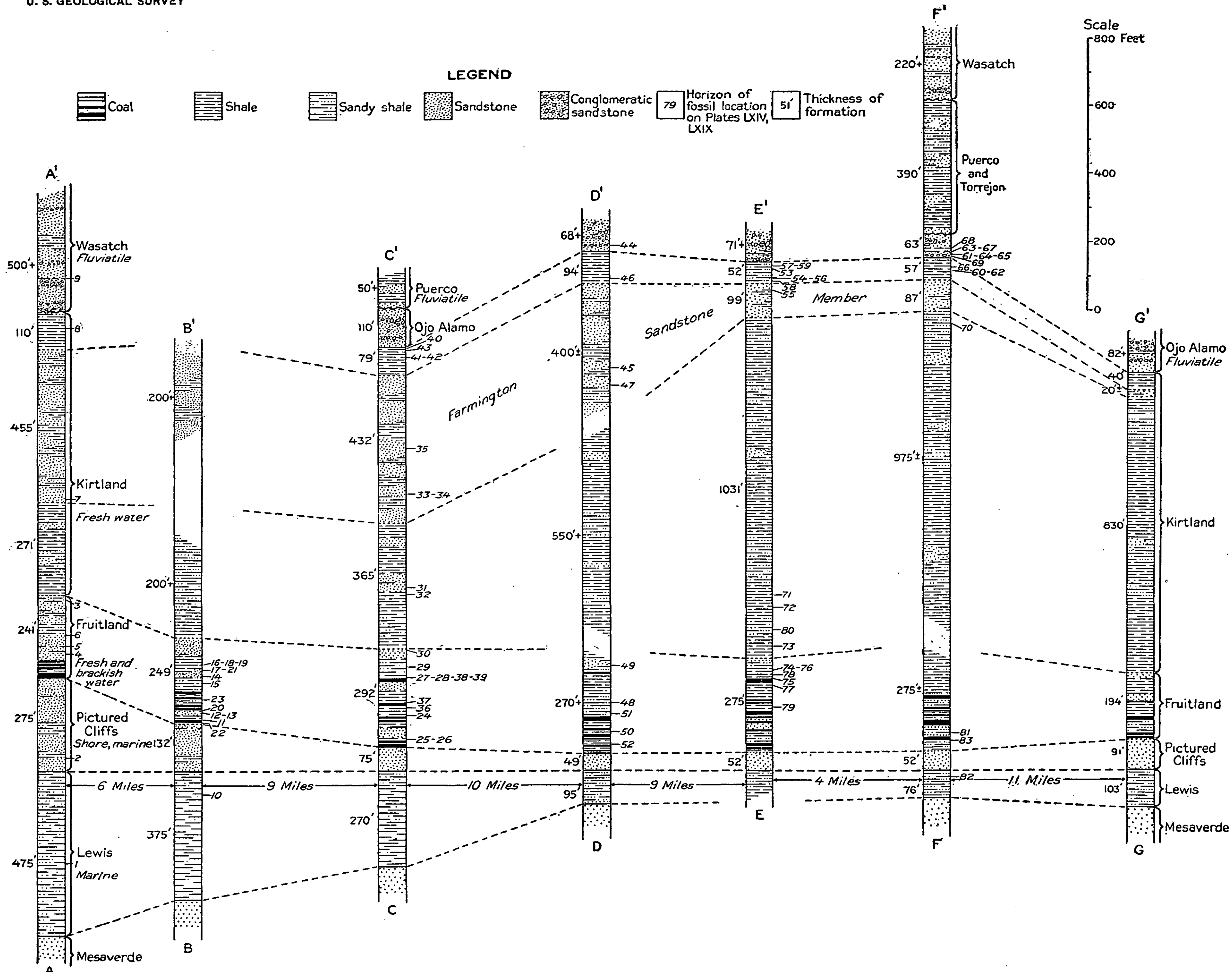
Marine Montana fauna.

FRUITLAND FORMATION.

Conformably above the Pictured Cliffs sandstone lie the brackish and fresh water beds of the coal-bearing Fruitland formation, and the contact presents the usual characteristics of interfingering beds. The name Fruitland is derived from that of a settlement on San Juan River which lies on the outcrop of this formation. The formation consists of sandstone, shale, and coal. (See Pl. LXVII, *B*.) It is very irregularly bedded, and the several beds range from sandy shale and shaly or clayey sandstone in all conceivable proportions to rocks that can be definitely called sandstone or shale. The variation in some places is so rapid both laterally and vertically that weathering of the unequally indurated rocks produces pillars, knobs, capped prisms, pyramids, and fantastic shapes of all sorts. This irregularity is most marked in the gray-white sandstone and gray sandy shale, but to some degree it affects also the coal beds. Nevertheless the coal beds, although they are lenticular, are more persistent than the sandstone and shale with which they are interbedded. Large concretions of iron carbonate which weather dark brown or black occur at several horizons. These concretions commonly contain barite, which has been introduced into them subsequent to the deposition of the strata, and many of them have in this manner been converted by veins of crystallized barite into large septaria. The Fruitland formation is more sandy than the overlying Kirtland shale, into which it merges by a gradational zone containing in many places sandstone lenses that are apparently of fluviatile origin. The thickness of the Fruitland formation is fairly constant in this field, ranging from 194 to 292 feet. (See Pl. LXV.) The fossils of this and the succeeding formations up to the Puerco are listed and discussed in the papers by Messrs Gilmore, Stanton, and Knowlton already mentioned.

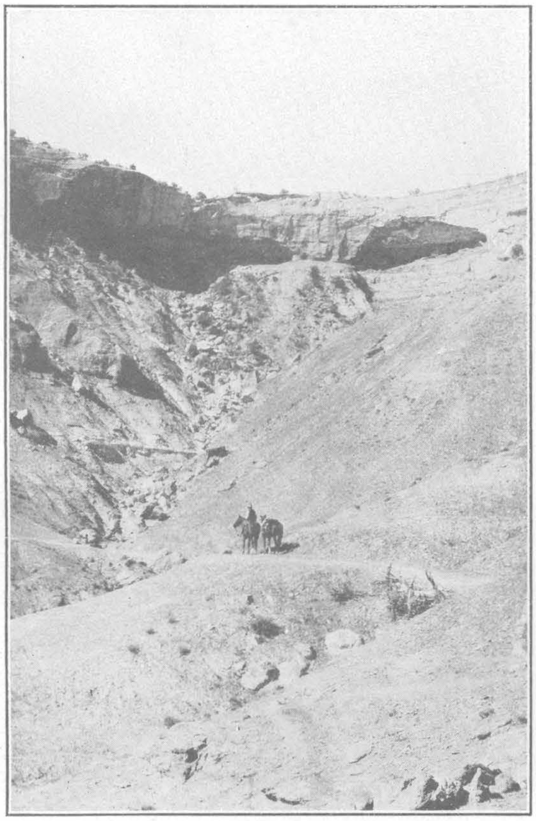
KIRTLAND SHALE.

The Kirtland shale lies conformably upon the Fruitland and is predominantly clayey. The name is taken from that of a post office on San Juan River. The strata are composed mostly of gray shale, with some brown, bluish, greenish, and yellowish shales, easily weathering gray-white sandstone, and the brown resistant sandstone of the Farmington member described below. Barite occurs in concretions and veins in these strata. The eroded surface of the Kirtland shale presents a billowy appearance, with well-rounded surfaces. It is readily affected by erosion, giving rise to extensive badlands. The shale, so far as known, is of fresh-water origin, although possibly it was formed in deltas and lagoons. It is divided, as shown in the San Juan River section (A–A′, Pl. LXV), into three parts—a lower shale 271 feet thick, a sandy part, here named the Farmington sandstone member (see Pl. LXVIII, *A*), and an upper shale 110 feet thick (see Pls. LXXI, *A*, and LXVI, *C*).

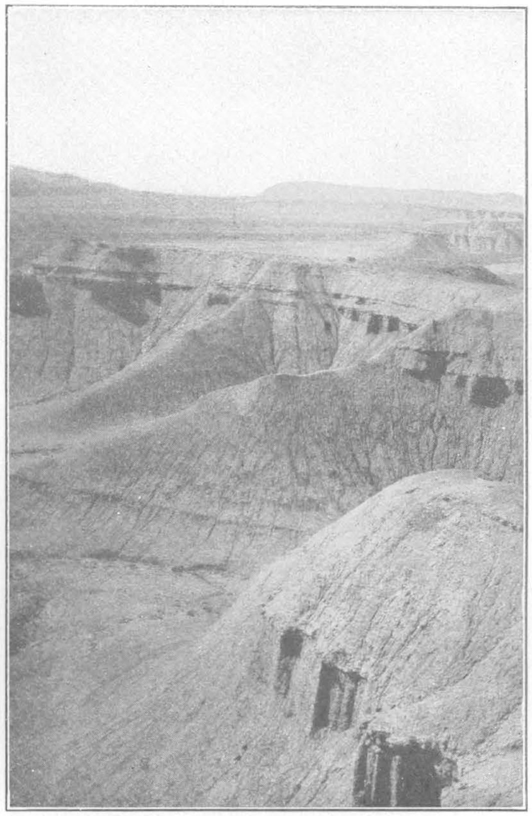


STRATIGRAPHIC SECTIONS ALONG CHACO VALLEY, N. MEX., FROM SAN JUAN RIVER TO MEYERS CREEK.

For locations see Plate LXIV.

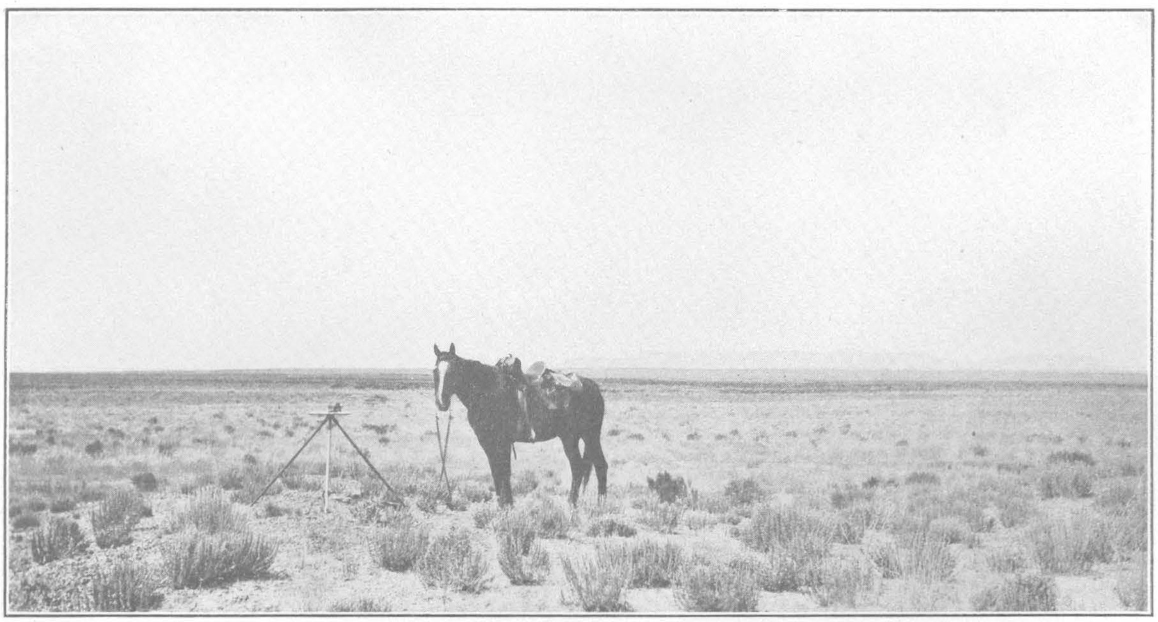


A. KIRTLAND SHALE OVERLAIN BY WASATCH FORMATION ON SOUTH SIDE OF SAN JUAN RIVER OPPOSITE FARMINGTON, N. MEX.



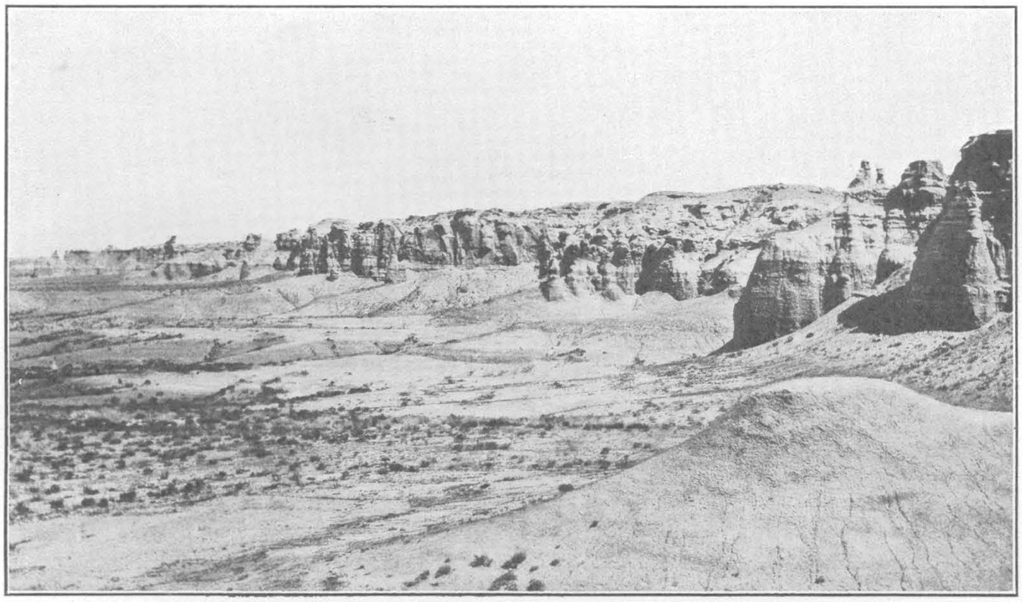
B. OUTCROP OF LEWIS SHALE ALONG CHACO RIVER, N. MEX., 1 MILE EAST OF POINT WHERE IT CUTS THROUGH THE GREAT HOGBACK.

The Great Hogback is composed of rocks of the Mesaverde formation and appears in the distance. Exposure shows sandy beds in the Lewis shale. View looking northwestward.



C. THE DESERT PLAIN VIEWED NORTHWESTWARD ACROSS THE VALLEY OF CHACO RIVER, N. MEX., SOUTH OF HUNTER WASH.

Chaco River and other arroyos are intrenched from 75 to 200 feet in this plain, which slopes westward 25 feet to the mile. The Great Hogback is seen in the distance. Elevation above sea level at plane table, 5,680 feet.

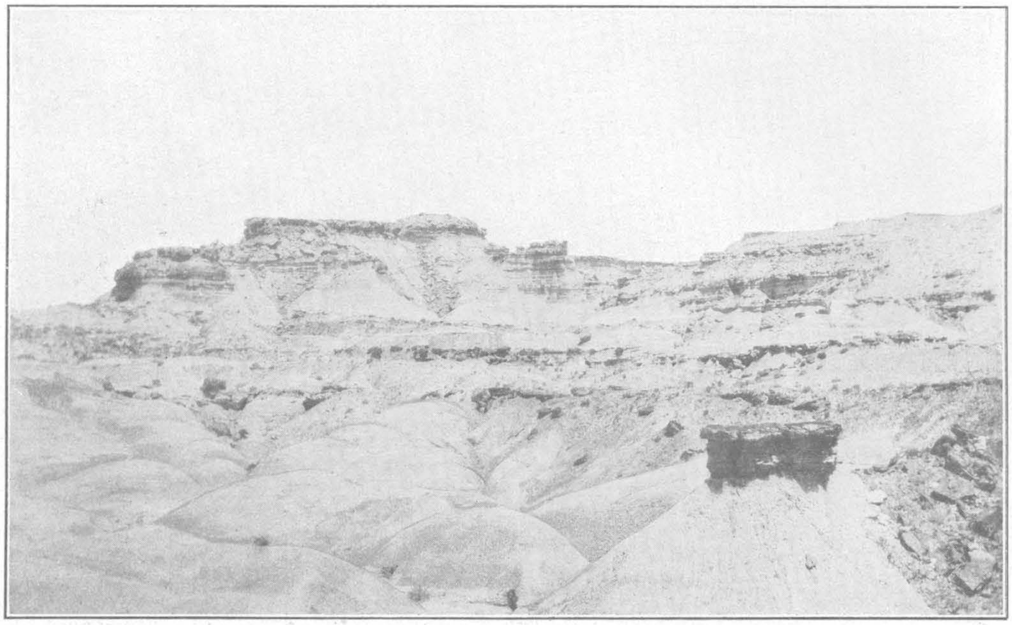


A. PICTURED CLIFFS SANDSTONE OVERLYING LEWIS SHALE ON NORTH SIDE OF COAL CREEK, N. MEX., 2 MILES FROM ITS MOUTH.

View looking westward.

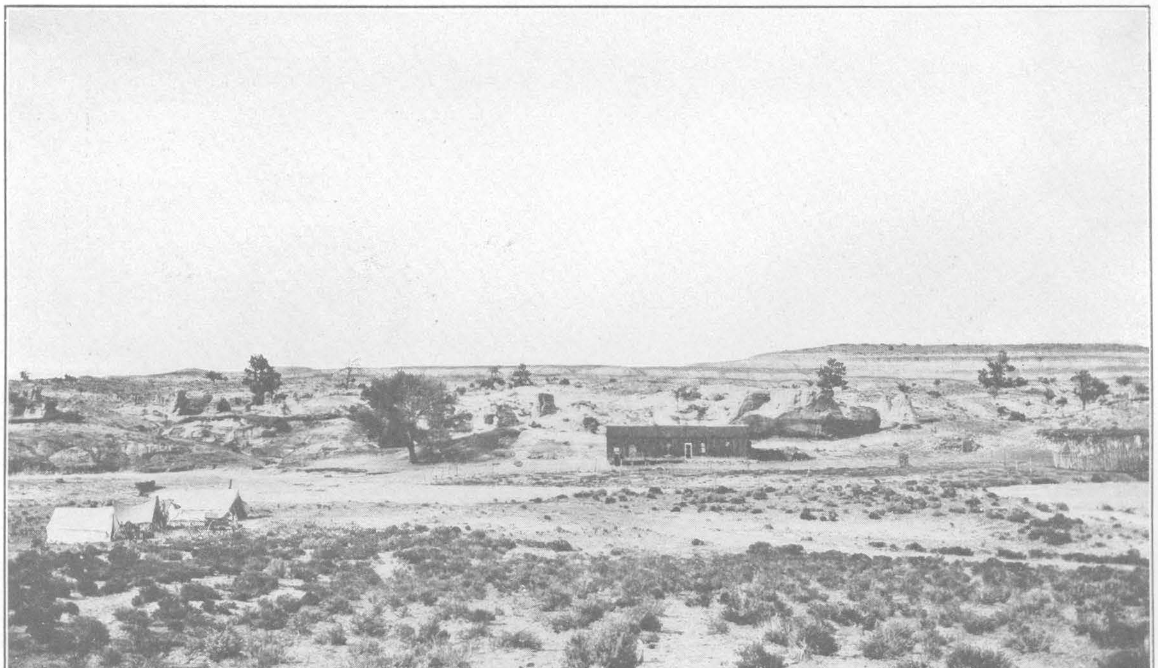
B. OUTCROP OF LOWER PART OF FRUITLAND FORMATION 1 MILE SOUTHWEST OF HUNTER'S STORE, N. MEX.

Coal bed is overlain by peculiarly weathered gray-white sandstone. Flat in foreground underlain by shale. View looking southeastward.



A. FARMINGTON SANDSTONE MEMBER OF KIRTLAND SHALE NEAR THE HEAD OF COTTONWOOD ARROYO, N. MEX.

Part of sandstone shown is 300 feet thick; upper part of Farmington sandstone, about 130 feet, is eroded at this place.



B. OJO ALAMO SANDSTONE AT OJO ALAMO STORE, N. MEX.

Puerco formation overlying Ojo Alamo sandstone is shown in the distance. View looking northward.

The sandstone member forms a prominent bluff on San Juan River, where it is 455 feet thick, but toward the south it is gradually replaced by lenses of shale. On the head of Coal Creek the member disappears as a mappable unit, and farther south it is represented only by isolated sandstone lenses in the Kirtland shale. A study of the sandstone lenses making up the Farmington shows that they are irregular in thickness, cross-bedded, and composed almost invariably of two parts—at the base an easily eroded yellowish sandstone carrying clay pellets of various sizes and in some lenses sandstone pebbles similar to the matrix, as large as 4 inches in diameter, and at the top a markedly resistant brownish sandstone whose upper portion is commonly of a dark chocolate-brown color on the exposed surface and dark gray on the fresh surface. All the lenses in the Farmington sandstone member lie on more or less irregular surfaces of interbedded shale and exhibit the characteristics of channel and flood-plain deposits. An individual lens will usually have a maximum thickness of 20 feet, a lateral extent of 15 or 20 yards, and a length of several hundred yards.

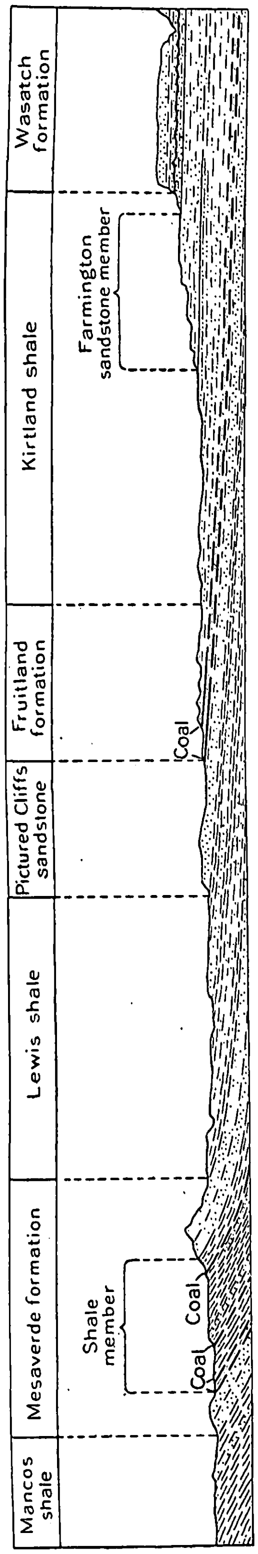


FIGURE 27.—Diagrammatic profile section along south side of San Juan River from the Great Hogback to top of bluff opposite Farmington, N. Mex.

The upper part of the Kirtland shale (see Pls. LXVII, *A*, and LXXI, *A*) is remarkably uniform in thickness from San Juan River to the southern limit of the area, ranging from 40 to 110 feet. It is composed of shale and lenses of easily weathered gray-white sandstone, and is thus very similar to the lower part. It is banded in many places with various colors, such as appear in the lower part of the Kirtland, but yellow, blue-gray, and purplish beds are more common.

OJO ALAMO SANDSTONE.

Overlying the Kirtland shale (see Pl. LXXI, *A*) with apparent conformity is a thin formation of conglomeratic sandstone and shale. These beds were first described by Barnum Brown,[1] of the American Museum of Natural History, New York, who named them Ojo Alamo, from the locality in which they were examined, but assigned no base and indicated no relation between them and the underlying beds. On Ojo Alamo Arroyo Brown found dinosaur-bearing shale below a conglomerate, which is overlain unconformably by the Puerco formation. The following statement is taken from his description:

> Less than a mile south of the store at Ojo Alamo the Puerco formation rests unconformably on a conglomerate that is composed of red, gray, yellow, and white pebbles. * * * Below the conglomerate there is a series of shales and sandstones, evenly stratified and usually horizontal. * * *
>
> The shales below the conglomerate that contain numerous dinosaur and turtle remains I shall designate as the Ojo Alamo beds. They were estimated to be about 200 feet thick, but owing to lack of time I was unable to determine their relation to the underlying formations.

Later Sinclair and Granger,[2] of the same institution, while making a thorough investigation of the Puerco formation, examined the Ojo Alamo locality, and found that the dinosaur-bearing shale on Ojo Alamo and Barrel Spring arroyos is split by a thin conglomerate, referred to by them as the "lower conglomerate."

According to their interpretation

> The Puerco formation rests with marked erosional unconformity on a coarse cross-bedded conglomeratic yellow-brown sandstone * * * which varies in thickness

[1] Brown, Barnum, The Cretaceous Ojo Alamo beds of New Mexico, with description of the new dinosaur genus Kritosaurus: Am. Mus. Nat. Hist. Bull., vol. 28, pp. 267-274, 1910.

[2] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297-316, 1914.

from 28 to 66 feet. [This sandstone] rests disconformably on * * * rusty-yellow, bluish, greenish, and wine-red banded clays with lenses of yellow channel sandstone. * * * A maximum thickness of some 58 feet was measured for this member. * * * [It contains] abundant but badly crushed dinosaur bones, ceratopsian, trachodont, and carnivorous, also turtles, crocodiles, and garpikes. [The sandstone lies on a "lower conglomerate," which] varies from a pebbly sandstone to a coarse conglomerate with waterworn, chatter-marked quartzite, jasper, andesite, and porphyrite pebbles. * * * Its source has not been traced. Its thickness varies from 6 to 8 feet. * * * This lower conglomerate lies in its turn disconformably on a series of bluish shales, or rather clay, for they are quite incoherent. * * * [This shale contains dinosaur bones.] A trip down Ojo Alamo Arroyo to a point some 8 miles below the store resulted in finding turtle and other reptile bones in shales apparently conformable with those just mentioned.

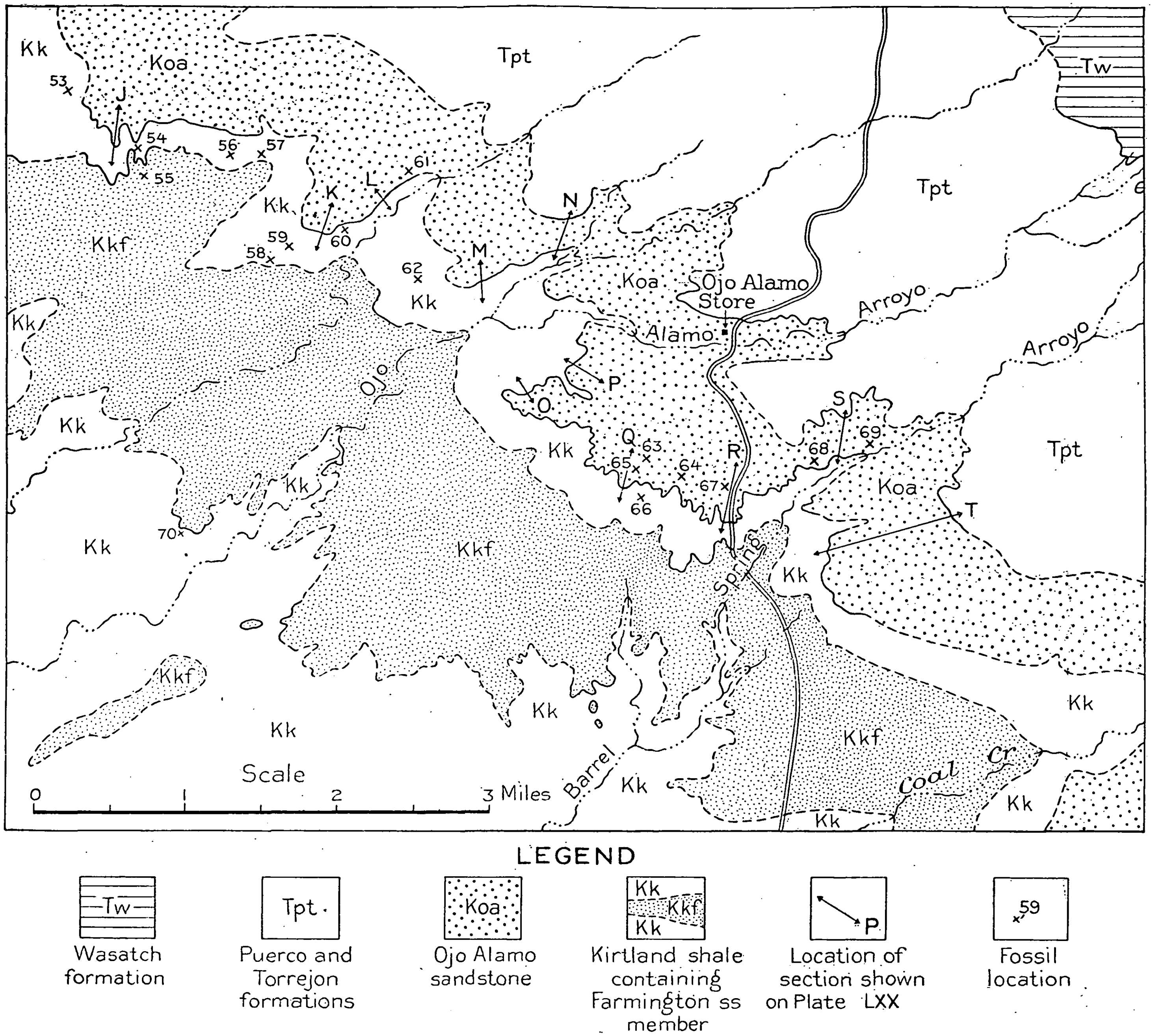
The discrepancies in these descriptions and the failure of these investigators to assign a stratigraphic or paleontologic lower limit to the Ojo Alamo beds call for a more accurate definition of them. The present writer, therefore, made a careful study of these beds in the type locality. Sections (lettered H to W on Pl. LXX; locations of H, I, U, V, and W shown on Pl. LXIV, and of J to T on Pl. LXIX) were measured and compared. On Ojo Alamo and Barrel Spring arroyos (see Pl. LXXI, *A*, and sections O to S, Pl. LXX) the succession of shale and conglomerate as described by Sinclair and Granger was noted. Section P, measured on Ojo Alamo Arroyo, shows 25 feet of the "upper conglomerate" (see Pl. LXVIII, *B*) lying on the 34 feet of wine-red and bluish-gray banded shales interbedded with lenses of gray-white, easily eroded sandstone. This in turn lies on 9 feet of poorly consolidated conglomerate, which has an irregular base, the irregularities amounting to 2 or 3 feet in a horizontal distance of 50 feet. Below the lower conglomerate is a bluish-gray to greenish-gray shale, banded here and there with purplish beds and gray-white sandstone lenses. This lower shale is lithologically similar to and conformable with the beds below. Both of the shales just mentioned contain dinosaur and turtle remains, as shown in section Q, measured on Barrel Spring Arroyo. However, the lower conglomerate has been traced laterally to points where the shale between it and the upper conglomerate is absent, and only a single lithologic unit is present. (See sections, Pl. LXX.) Moreover, the lower shale of Sinclair and Granger is lithologically like the shale below the lower conglomerate on Ojo Alamo Arroyo and is clearly a part of the Kirtland shale. Furthermore, the shale that lies between the conglomerate beds on Ojo Alamo and Barrel Spring arroyos is cut in many places by irregular lenses of gray-white, easily eroded sandstone, which give it so irregular and indefinite an outline that it is not mappable. At localities H, I, J, L, M, T, U, V, and W this shale is not a definite unit.

As Brown, Granger, and Sinclair do not agree on the upper limit of the formation, Brown placing it at the base of the "upper conglomerate" and Sinclair and Granger at the top, and as neither of them assigned a lower limit, it is necessary to redefine the lithologic Ojo Alamo as determined by the writer. As he found the formation to be essentially a sandstone including lenses of shale and conglomerate, it seems desirable to call it Ojo Alamo sandstone and to define it as consisting on Ojo Alamo Arroyo of two conglomeratic beds and the shale lenses which they include. Its thickness where it is overlain by the Puerco formation (see sections H, N, S, and T) ranges from 63 to 110 feet.

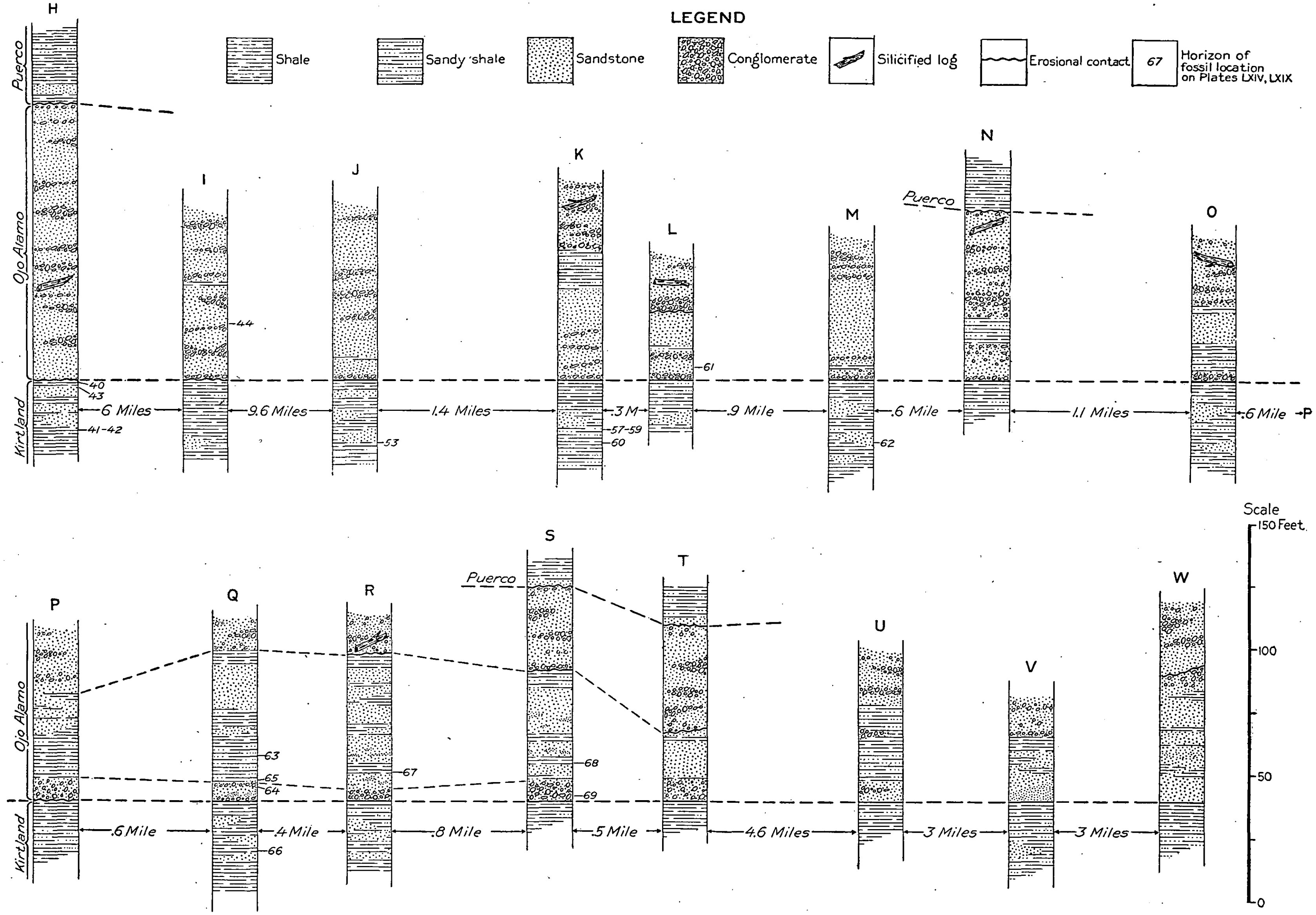
About 70 per cent of the pebbles of the Ojo Alamo are of jasper, variously colored chert, or pink or white quartzite. Of the remainder, pebbles of sandstone, andesite, felsite, porphyrite, gneiss, and schist are fairly common, and pebbles of granite and obsidian are also present. Practically all the pebbles are well rounded. They range in size from sand grains to a few that are 6 inches in diameter. The Ojo Alamo sandstone is highly cross-bedded, and the pebbles occur at different horizons or are scattered through it irregularly. In some places the lower 20 or 30 feet of it is almost lacking in pebbles. On Ojo Alamo Arroyo the lower bed of conglomerate is poorly consolidated, but on the south side of Barrel Spring Arroyo it is quartzitic and very resistant, capping several low buttes in the vicinity. Between localities U and V also the lower bed is very resistant, forming the cap rock for many small buttes.

PUERCO AND TORREJON FORMATIONS.

The Puerco formation (see Pls. LXVIII, *B*, and LXXI, *B*) overlies the Ojo Alamo sandstone with an unconformity by erosion, the irregularity in the contact where seen amounting to 15 or 20 feet, but no discordance of dips between the two formations was noted.



MAP SHOWING DETAILS OF GEOLOGY IN VICINITY OF OJO ALAMO, N. MEX.



SECTIONS OF OJO ALAMO SANDSTONE FROM PINA VETA CHINA TO THE HEAD OF MEYERS CREEK, N. MEX.

For locations see Plates LXIV and LXIX.

Considerable interest has been attached to the Puerco formation because of the primitive mammalian fauna which it contains and because it is confined, so far as known, to the San Juan Basin in New Mexico, though Torrejon mammals have been collected from the Fort Union of Montana.[1]

The Puerco was first described by Cope [2] in 1875. He believed it to overlie the "Laramie" conformably [3] on evidence presented to him by David Baldwin, a collector, who obtained most of the fossils from the Puerco for Cope. However, Cope also states in his paper on the Eocene plateau that the Eocene Wasatch overlies the Puerco "with apparent conformability."

Endlich [4] and Holmes,[5] in their early reconnaissance work in Colorado and New Mexico, apparently mistook the Kirtland shale, or, as Gardner [6] suggests, the lower members of the Wasatch, for the Puerco, inasmuch as typical Puerco mammals have not been found outside of a small area near the center of the San Juan Basin in New Mexico and have not been found in the deposits described by Endlich and Holmes.

The collecting by Baldwin under Cope's direction was actively carried on at intervals from 1880 to 1885, and numerous articles on the fauna were published. In 1892 J. L. Wortman took up the problems connected with the Puerco and headed an expedition to the San Juan Basin. His results were summarized in a paper by Osborn and Earle,[7] in which is quoted a statement from Wortman's notebook that "the Puerco beds so far as can be observed lie conformably upon the Laramie." Wortman again visited the region in 1896 and added much to the collections already obtained. W. D. Matthew [8] then began a systematic study of the Puerco fauna, and in 1897 his paper on it was published.

[1] Douglass, Earl, The discovery of Torrejon mammals in Montana: Science, new ser., vol. 15, pp. 272–273, 1902.

[2] Cope, E. D., The Eocene plateau: Chief Eng. Ann. Rept. for 1875, pt. 2, Appendix G1, ch. 6, pp. 1008–1017.

[3] Cope, E. D., The relations of the Puerco and Laramie deposits: Am. Naturalist, vol. 19, pp. 985–986, 1885.

[4] Endlich, F. M., The San Juan region: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1375, pp. 189–190, 1877.

[5] Holmes, W. H., La Plata Valley: Idem, pp. 245–267.

[6] Gardner, J. H., The Puerco and Torrejon formations of the Nacimiento group: Jour. Geology, vol. 18, No. 8, pp. 702–741, 1910.

[7] Osborn, H. F., and Earle, Charles, Fossil mammals of the Puerco beds, collection of 1892: Am. Mus. Nat. Hist. Bull., vol. 7, pp. 1–2, 1895.

[8] Matthew, W. D., A revision of the Puerco fauna: Am. Mus. Nat. Hist. Bull., vol. 9, pp. 259–323, 1897.

In 1907 J. H. Gardner,[9] in connection with the mapping of the coal beds in this area, made some observations on the Puerco. His conclusions were published in 1910.[10] His work was followed by the careful study of the Puerco and Torrejon formations, including extended collecting, in 1912–13 by Walter Granger and W. J. Sinclair, whose stratigraphic results were published in 1914.[11]

The Puerco formation was not studied in detail by the present writer, and only its general features will be set forth here. It is very lenticular and irregular in bedding and, like the underlying beds, is of fluviatile origin. It consists of clay, sandy shale, easily weathered sandstone, and resistant sandstone. The striking feature of the Puerco formation, aside from its mammalian fauna, is its color, which is predominantly bluish gray and gray-white, but banded with lemon-yellow sand and wine-red clay. It contains also lenses and concretions of resistant sandstone cemented with manganese dioxide, which are almost black and present a bold contrast to the other strata of the region. Barite is common in isolated concretions, as well as in veins and in sheets.

The Puerco is overlain by the Torrejon formation, which is very similar to it lithologically and was not separated from it by the writer in mapping. Owing to the close similarity in lithology such separation of the Puerco and Torrejon (see Pl. LXXI, *B*) as has been made in the past has depended entirely on fossil collections,[12] and although the fossils seem to indicate an unconformity between the two formations the writer has yet found no stratigraphic reason for such division.

WASATCH FORMATION.

The Wasatch formation, which probably exceeds 2,000 feet in thickness in the San Juan Basin, overlies the Torrejon unconformably and overlaps upon the Ojo Alamo and Kirt-

[9] Gardner, J. H., The coal field between Gallina and Raton Spring, N. Mex., in the San Juan coal region: U. S. Geol. Survey Bull. 341, pp. 335–351, 1909.

[10] Gardner, J. H., The Puerco and Torrejon formations of the Nacimiento group: Jour. Geology, vol. 18, No. 8, pp. 702–741, 1910.

[11] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297–316, 1914.

[12] Matthew, W. D., A provisional classification of the fresh-water Tertiary of the West: Am. Mus. Nat. Hist. Bull., vol. 12, pp. 19–77, 1899.

land formations. It consists of an alternation of conglomerate, conglomeratic sandstone, and shale. The basal member of the formation on San Juan River (see Pl. LXVI, *A*) has a thickness of 80 to 100 feet and consists of a well-indurated conglomeratic sandstone which contains pebbles of crystalline, volcanic, and sedimentary rocks. The pebbles range from sand grains to pebbles 8 inches in diameter and, together with the cross-bedding of the formation, suggest deposition by fairly rapid streams. This lower member of the Wasatch is separated from a similar member above it by 50 to 75 feet of greenish-gray and yellowish sandy shale and a few thin beds of carbonaceous shale. This alternation of shale and conglomeratic sandstone is repeated many times in the section exposed along San Juan River. The formation was not studied in detail and only its base was mapped. One collection of fossil leaves from the Wasatch at locality 9 (see Pl. LXIV) is discussed below by F. H. Knowlton:

This material is very fragmentary. It includes, apparently, two ferns, one Pteris-like and the other Anemia-like, but neither is sufficiently well preserved to be identified. There is also a monocotyledon that may be a palm ray or a large leaf of a sedge. The only dicotyledon present is a Sapindus not unlike a large leaflet of *S. angustifolia* Lesquereux, a Green River species.

This lot appears to be Tertiary, but it is too fragmentary to place positively.

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Holmes, W. H., Geology of the San Juan district: Idem, pp. 241–244.

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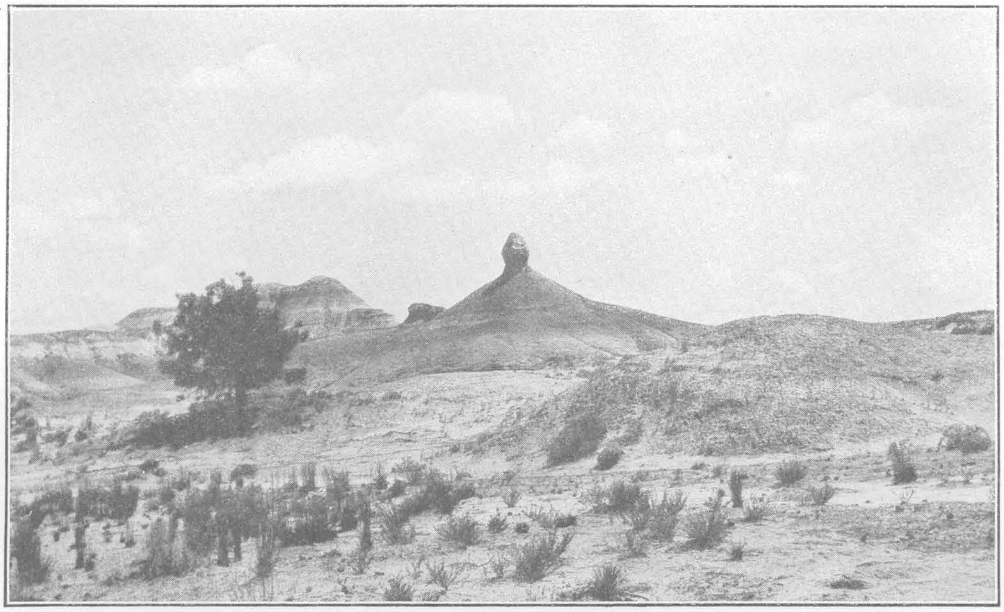
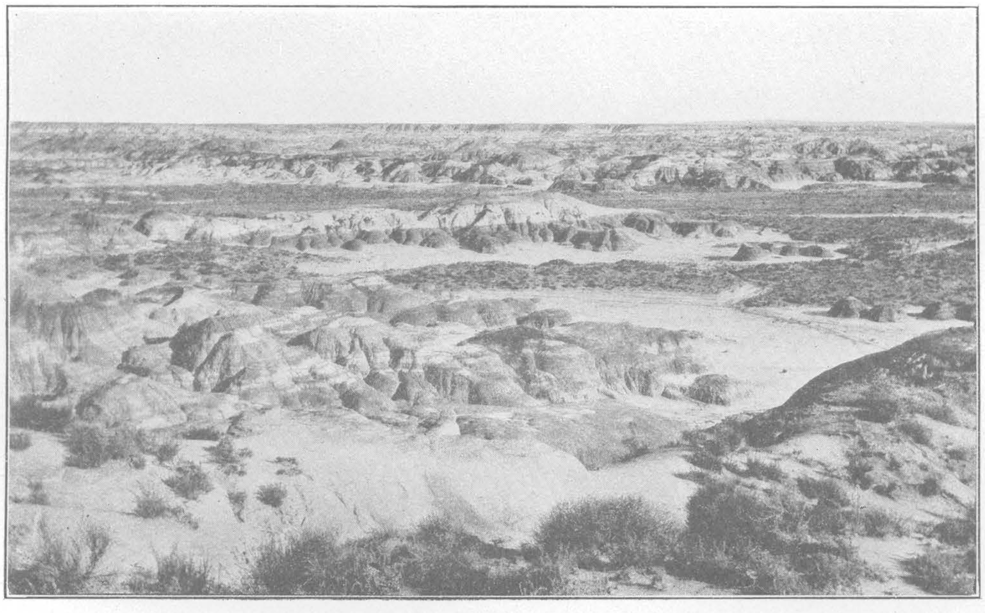


A. VIEW EASTWARD FROM DIVIDE BETWEEN OJO ALAMO AND BARREL SPRING ARROYOS, N. MEX.

Kirtland shale in foreground. Conical butte capped with lower part of Ojo Alamo sandstone. Butte at left consists of Kirtland shale at base, overlain by conglomeratic sandstone of Ojo Alamo, and that in turn by the middle or shale member of the same formation, with pebbles from the disintegrated upper conglomeratic member scattered over the top.



B. EXPOSURE OF PUERCO AND TORREJON FORMATIONS MAKING BADLANDS 1½ MILES ABOVE STORE ON OJO ALAMO ARROYO, N. MEX.

Sky line in center of view shows evenness of interstream areas, which form a westward-sloping plain along Chaco River, the same plain as that shown in figure 27. Altitude of plain, about 6,400 feet.

2. VERTEBRATE FAUNAS OF THE OJO ALAMO, KIRTLAND, AND FRUITLAND FORMATIONS.

By Charles W. Gilmore.

INTRODUCTION.

The presence of dinosaurian fossil remains near Ojo Alamo, in the northwestern part of the San Juan Basin, N. Mex., was first reported by George Pepper, of the Hyde Exploring Expedition, in 1902. Dinosaurian fossils from the San Juan Basin were known, however, as early as 1885. Cope[1] identified, in collections made by David Baldwin, teeth pertaining to the genera Dysganus, Lælaps, and Diclonius. None of these are now recognized as valid genera. In 1904 Barnum Brown, of the American Museum of Natural History, New York, made a short reconnaissance trip into this region and procured a small but interesting collection of vertebrate fossils, including specimens that were later made the types of *Kritosaurus navajovius* Brown, *Thescelus rapiens* Hay, *Aspideretes fontanus* Hay, *A. vorax* Hay, and *A. austerus* Hay. In 1908 James H. Gardner, while engaged in field work for the United States Geological Survey, made a small collection of fragmentary vertebrate remains, and the next summer, 1909, accompanied by J. W. Gidley, of the United States National Museum, he obtained a second small collection. Two of the turtle specimens collected by Mr. Gardner were selected by O. P. Hay as the types of the species *Adocus vigoratus* Hay and *Basilemys nobilis* Hay.

In 1912 Walter Granger and W. J. Sinclair visited this region and as an incidental part of their work in the overlying Puerco and Torrejon deposits made a small collection of reptilian fossils from the Ojo Alamo sandstone, in which a second specimen of *Kritosaurus navajovius* was recognized and bones of Monoclonius and Deinodon were noted for the first time.

During the field season of 1915 a party under the leadership of C. Max Bauer, assisted by J. B. Reeside, jr., made the most extensive and best collection of fossil vertebrate remains yet procured from this area.

[1] Cope, E. D., The relations of the Puerco and Laramie deposits: Am. Naturalist, vol. 19, pp. 985-986, 1885.

In the present paper I have brought together all the information obtainable relating to the extinct vertebrate fauna of the Ojo Alamo sandstone and of the deposits that immediately underlie that formation. A considerable number of genera and species have now been described in widely scattered publications, and these descriptions are here compiled as an aid to future students.

O. P. Hay and Barnum Brown have been the chief contributors to our knowledge of this fauna, and I have made free use of their articles. The original descriptions of such genera or species as have been established on specimens from these deposits are given in full, followed by such comments and emendations as more recent discoveries and additional material render possible.

I wish here to acknowledge my indebtedness to Dr. L. M. Lambe, of the Geological Survey of Canada, and Dr. W. D. Matthew, of the American Museum of Natural History, New York, for furnishing me with excellent photographs of the skulls of Gryposaurus and Kritosaurus, here reproduced; and to Mr. Barnum Brown, also of the American Museum of Natural History, for valuable assistance in identifying specimens.

THE VERTEBRATE FAUNA.

The known vertebrate fauna of the dinosaur-bearing beds in the San Juan Basin in northern New Mexico consists of a considerable number of genera and species, but many of them have been identified from material so insufficient and fragmentary that it is quite impossible to define them properly. A few, however, are fairly diagnostic, so that comparison with related forms of other geologic formations serves to give some clue as to the age of the deposits from which these specimens were obtained.

In the preceding paper of this series Mr. Bauer has subdivided the dinosaur-bearing deposits into three formations—(1) the uppermost, or Ojo Alamo, as named by Brown,[1] now restricted to include only the upper sandstone, conglomerates, and interbedded shale lenses, (2) the Kirtland, and (3) the Fruitland. Vertebrate fossils are found throughout these deposits, though they appear to occur most abundantly in the Ojo Alamo and the upper part of the Kirtland, sparsely in and below the Farmington sandstone member of the Kirtland, and more abundantly in the Fruitland.

Material is not yet available for determining whether these formations can be said to carry distinctive vertebrate faunas. The faunas as now known are as follows:

Ojo Alamo sandstone:
- Dinosauria:
  - Kritosaurus navajovius Brown.
  - Monoclonius sp.
  - Deinodon?
- Chelonia:
  - Basilemys nobilis Hay.
  - Adocus? vigoratus Hay.
  - Aspideretes vorax Hay.
  - Aspideretes fontanus Hay.
  - Aspideretes austerus Hay.
  - Thescelus rapiens Hay.
  - Compsemys sp.
- Crocodilia:
  - Crocodiles.
- Pisces:
  - Lepisosteus sp.

Kirtland shale:
- Dinosauria:
  - Kritosaurus navajovius Brown.
  - Carnivorous dinosaurs.
  - Ceratopsian dinosaurs.
  - Armored dinosaur (Ankylosauridæ).
- Chelonia:
  - Baena nodosa n. sp.
  - Neurankylus baueri n. sp.
  - Aspideretes sp.
  - Adocus sp.
  - Plastomenus sp.
- Crocodilia:
  - Crocodiles.
  - Brachachampsa sp.
- Pisces:
  - Lepisosteus sp.
  - Myledaphus sp.

Fruitland formation:
- Dinosauria:
  - Monoclonius?
  - Carnivorous dinosaurs.
- Chelonia:
  - Adocus? lineolatus Cope.
  - Aspideretes austerus Hay.
- Pisces:
  - Lepisosteus sp.

[1] Brown, Barnum, The Cretaceous Ojo Alamo beds of New Mexico, with description of the new dinosaur genus Kritosaurus: Am. Mus. Nat. Hist. Bull., vol. 28, pp. 267-268, 1910.

No mammal, bird, or amphibian remains have yet been recorded from these formations. The fishes are represented by two genera, Lepisosteus and Myledaphus, neither of which have any value in correlation. The same may be said of the Crocodilia. The Chelonia are the best represented, nine genera and eight species having been recognized, and systematic collecting would doubtless add several more. Unfortunately, more than half of the described species have been founded upon fragmentary material, and it is with difficulty that they are compared with better-preserved specimens of other geologic horizons. With the exception of *Adocus? lineolatus* Cope all the recognized species have been based on specimens collected from these formations, so that they offer but little aid in correlation. The discovery in the Kirtland shale of the genus Neurankylus is significant, as previously it has been known by a single specimen from the Belly River formation. *Basilemys nobilis* Hay, from the Ojo Alamo, has its closest affinities in an undescribed specimen from the Two Medicine formation, of Montana, a formation that is in part equivalent to the Judith River. According to Hay, *Thescelus rapiens* appears to approach *Thescelus insiliens* from the lower Lance, but *Baena nodosa* offers no close comparisons.

The dinosaurs were apparently the predominating vertebrates of these times, and they afford the best basis for a comparison with forms found elsewhere. The Trachodontidæ and Ceratopsidæ give the most information relative to the age of these deposits. The finding of the genus Kritosaurus, known elsewhere only from the Belly River; the presence of trachodont teeth with papillate borders, a condition heretofore found only in forms from the Niobrara, Judith River, Belly River, Two Medicine, and Edmonton formations; and the finding of maxillæ having 42 rows of teeth, whereas none of the known specimens from the Lance formation have less than 52 vertical rows, all constitute a combination of evidence showing a greater antiquity than Lance time for the beds from which these specimens were obtained.

The Ceratopsia give corroborative evidence of this conclusion, as shown by specimens found in the Ojo Alamo and Fruitland formations which are provisionally identified as pertaining to the genus Monoclonius. Regardless of the uncertainty of the generic designation of these specimens, they unquestionably represent the so-called primitive ceratopsians, none of which are found in beds younger than the Edmonton.

Brown [1] has recently said, in regard to the age of the Ojo Alamo formation:

> The vertebrate fauna is distinctly older than that of the Lance. I have expressed the opinion that it was comparable to the Edmonton, but from the recent discovery of Kritosaurus in the Belly River formation and the primitive structure of the contemporary dinosaurs the Ojo Alamo beds appear to be synchronous with the Judith (Belly River) formation.

These conclusions were based by Brown on specimens collected in the upper 200 feet of deposits that immediately underlie the Puerco, and it is quite likely that some of these forms came from beds now included in the Kirtland shale. However that may be, Brown has now established the geologic position of the type of *Kritosaurus navajovius* as below the lower conglomerate and therefore in the Kirtland shale, but the subsequent discovery of a second specimen of the same species above the lower conglomerate shows that the basis for his original contention is not altered by this later subdivision of the deposits. In the Bauer collection of 1915 was a ceratopsian ischium from the Ojo Alamo sandstone identified as pertaining to Monoclonius, a Judith River and Belly River genus. This occurrence and the presence in the same formation of the turtle *Basilemys nobilis* Hay, which has its closest affinities with a Two Medicine form, both support Brown's contention.

Although much is needed in the way of better material before it will be possible to determine even approximately the vertebrate faunas of the Ojo Alamo and underlying formations, enough is already known to indicate their diversity. The discovery of two new species of turtle, *Neurankylus baueri* and *Baena nodosa*, seems to indicate that a careful and systematic search of these areas for vertebrate remains would be well rewarded.

After a study of the material in the United States National Museum collections from this area, and after reviewing the literature in which specimens from these formations have been described, I conclude that the vertebrate remains from the Ojo Alamo, Kirtland, and Fruitland formations show beyond all question that they pertain to a fauna or faunas distinctly older than that of the Lance, and that such evidence as there is contributes to the support of Brown's contention that the Ojo Alamo sandstone is synchronous with the Judith River and Belly River formations as found in areas to the north.

Class REPTILIA.

Order DINOSAURIA.

That the deposits in the San Juan Basin contain a rich dinosaurian fauna is clearly indicated by the discovery of numerous fragmentary remains at many localities. In the collection made by Mr. Bauer in 1915 specimens sufficiently perfect to be identified as dinosaurian were found in no less than 35 localities and at several horizons. These specimens consist chiefly of limb bones, vertebræ, skull fragments, and detached teeth. The greater number of them were chalcedonized, a condition common in the Two Medicine formation of northwestern Montana and, as Brown [2] has pointed out, also "in the Judith River, but never observed in the Laramie." (By "Laramie" I take it he means the Lance.) Only two of the three suborders into which the Dinosauria are subdivided have yet been recognized. The Predentata are represented by trachodont and ceratopsian remains, and the Theropoda, or flesh-eating dinosaurs, by numerous detached teeth and fragmentary bones. Specimens representing the Ornithopoda, or "bird-footed" dinosaurs, have not yet been found, but it may be confidently expected that larger collections will contain representatives of this group also.

Suborder PREDENTATA.

Family TRACHODONTIDÆ Marsh.

Kritosaurus navajovius Brown.

Plate LXXII, *A*; Plate LXXIII, figures 3 and 5.

Kritosaurus navajovius Brown, Am. Mus. Nat. Hist. Bull., vol. 28, pp. 269–274, pls. 28, 29, text figs. 2–7, 1910.
Sinclair and Granger, Am. Mus. Nat. Hist. Bull., vol. 33, pp. 301, 303, 1914.
Brown, Geol. Soc. America Bull., vol. 25, p. 380, 1914.

The present genus and species were founded upon a weathered skull, lower jaws, and atlas, of

[1] Brown, Barnum, Cretaceous-Eocene correlation in New Mexico, Wyoming, Montana, and Alberta: Geol. Soc. America Bull., vol. 25, p. 380, 1914.

[2] Brown, Barnum, The Cretaceous Ojo Alamo beds of New Mexico, with description of the new dinosaur genus Kritosaurus: Am. Mus. Nat. Hist. Bull., vol. 28, p. 268, 1910.

which the skull and jaws are shown in Plates LXXII, *A*, and LXXIII, figure 5. It was described by Brown as follows:

Type of species, No. 5799, American Museum collection.

Generic characters.—Skull deep; muzzle narrow; frontals short, orbital portion reduced, barely coming to the border of the orbit; nasals and premaxillaries very long, quadrate elongate; quadratojugal short anteroposteriorly, completely separating quadrate and quadratojugal. Mandibular rami massive; edentulous portion decurved. Teeth spatulate in lower jaw.

Specific characters.—Maxillary teeth smooth on borders. Mandibular teeth papillate on borders, median carina low, predentary deep and massive. Free edentulous portion of dentary not covered by predentary, short.

The skull is that of an old individual, and most of the sutures are obliterated by exfoliation. When found it was almost completely weathered out and the anterior end was in a very fragmentary condition. It was impossible to place many of these fragments in the restoration and where there was no contact the bones were left out. The dentary and predentary were perfectly preserved, thus determining the length of the skull. The nasals were restored after the skull of Trachodon (Diclonius) Cope, and the premaxillaries according to the relative size between the predentary and premaxillary in that species, which necessarily made the rostrum much deeper.

SKULL.

The skull is very deep and more massive than in any heretofore-described species of the family, and its elements in general follow the Trachodon form, but with the following distinct modifications: Premaxillaries and rostrum proportionately shorter than in *Trachodon* (*Diclonius*) *mirabilis or Claosaurus annectens* Marsh. Frontal short anteroposteriorly, prefrontal and postfrontal almost excluding it from the border of the orbit. Paroccipital process of exoccipital actually and relatively longer than in Trachodon. Orbital opening proportionately smaller and laterotemporal fenestra proportionately larger than in Trachodon. Quadrate and jugal completely separated by quadratojugal, the exposed part of which is short anteroposteriorly and vertically high. Ectopterygoid extending forward to the union of the maxillary and the jugal.

LOWER JAW.

The lower jaw in form resembles more closely Judith River than Laramie [Lance] species. Its edentulous portion not covered by predentary is shorter than in any Laramie [Lance] form.

Predentary.—The two predentaries are firmly coossified, forming a single element, but clearly show their union in the median line. Its lateral borders are massive and nearly vertical, forming a powerful clipping instrument, whereas in all Laramie [Lance] forms they are delicate and conform to the shape of the rostral bones. The anterior upper border is very rugose and is perforated by two parallel series of vascular foramina, resembling alveoli, but which pass obliquely downward and open on the outer surface. Each arm of the ∩ terminates in a short rounded inner and a longer outer process. On the posterior lower border in the center there are two processes, an inner short, free tonguelike process which separates the upper anterior ends of the dentaries and a longer, wider process which underlies the symphysis. The latter process is broken near its origin and shows no indication of bifurcation.

Dentary.—This element is very massive. The edentulous portion is about one-fourth of its entire length, is strongly decurved, and near the symphysis curves inward. The coronoid process rises opposite the last row of teeth, as in the genus Trachodon, but the backward prolongation of the surangular gives it the appearance of being further forward. It is intermediate in position, in relation to the complete mandible, between Trachodon and the European genus Hecatasaurus.[1]

Surangular.—The surangular is proportionately longer than in Trachodon. Its anterior vertical process is truncated obliquely and expanded to continue the posterior lower border of the coronoid process. Posteriorly it broadens and furnishes four-fifths of the articular surface for the quadrate.

Articular.—The articular forms the extreme end of the jaw and is wedged in between the posterior ends of the surangular, angular, and splenial. It furnishes about one-fifth of the articular surface for the quadrate, in front of which it contracts to a thin wedge but does not reach forward to the end of the dentary process.

Splenial.—The splenial follows the usual Trachodon form.

Angular.—The angular is very long and narrow. Posteriorly its lower border is visible on the outside of the jaw. Anteriorly it forms the lower border of the Meckelian groove and extends nearly to the middle of the dentary.

TEETH.

Two distinct types of teeth appear in the family Trachodontidæ. In the earliest representatives known, *Claosaurus agilis* Marsh, from the Niobrara, and species from the Judith River beds that have been referred to Trachodon, the enamel face of mandibular teeth is spatulate in form and papillate on the borders. In the larger Laramie [Lance] Cretaceous species the enamel face of the mandibular teeth is diamond-shaped, with smooth borders.

The teeth of *K. navajovius* are of the primitive form. [See Pl. LXXIII, fig. 3.] Both upper and lower series, respectively, are larger than in any described species of the family. In the mandibular series there are 42 vertical rows of teeth. On the triturating surface one tooth, enamel bearing, a half-worn tooth, and an indefinite number of worn roots appear in each row. The enamel face of each tooth is spatulate and rather sharply pointed at the summit; median carina low; lateral surface flat; borders not raised above the flat surface and sparsely studded with enamel papillæ that apparently lack definite arrangement.

In the maxillary series there are 47 vertical rows, and never more than two enamel-bearing teeth appear on the triturating surface in each row. They are smooth on the borders and very strongly curved transversely; median carina very high.

[1] To replace Limnosaurus Nopcsa, 1900; preoccupied by *Limnosaurus ziphodon* Marsh, 1871, Acad. Nat. Sci. Philadelphia Proc., vol. 23, p. 104. Type, *Limnosaurus transsylvanicus* Nopcsa, Akad. Wien Denkschr., vol. 68, pp. 555-591, 1900.

MEASUREMENTS.

Skull.

	Millimeters.
Length, as restored	995
Width across frontal above orbits	220
Width across proximal ends of quadrate	350
Width across distal ends of quadrate	490
Frontal, length anteroposteriorly	198
Parietal, length	113
Supratemporal vacuity, length	140
Supratemporal vacuity, width	100
Quadrate, height	516
Quadratojugal, exposed, length anteroposteriorly	42
Quadratojugal, exposed height	160
Ectopterygoid, length	190

Lower jaw.

Length without predentary	775
Predentary, length	240
Angular, length	250
Splenial, length	260
Articular, length	95

Teeth.

Dental series, upper jaw, length	410
Tooth, mid-section, lower jaw, length	45
Tooth, mid-section, lower jaw, width	15

Four years later Lambe [1] described the new genus and species *Gryposaurus notabilis*, from the Belly River formation of Canada, based on a beautifully preserved skull (see Pl. LXXII, *B*), with which was associated a considerable part of the skeleton, including some areas of skin impressions. In a report made to Sinclair and Granger and included in their paper on the Paleocene deposits of the San Juan Basin [2] Brown calls attention to the description of *Gryposaurus notabilis* Lambe, and remarks: "In all respects, including the remarkable development of the nasals, premaxillaries, and predentary and reduction of the orbital portion of the frontal, this skull agrees with the type of Kritosaurus, and there is no doubt of their identity."

In this conclusion Brown is undoubtedly correct, but in justice to Lambe it should be explained that, although Brown had one of the characteristic nasal bones, it was not inserted in the restored skull as figured by him (see Pl. LXXII, *A*), because there was no contact with contiguous parts, and the absence of this portion undoubtedly led Lambe into the unfortunate error of establishing a genus which now proves to be a synonym of the earlier described Kritosaurus.

As has been pointed out by Brown, the discovery of Kritosaurus in the Kirtland and Ojo Alamo beds has an important bearing on the relative age of these formations and would appear to indicate that they are synchronous with the Judith River formation.

In his original paper Brown failed to state the geologic level where the type specimen was found, but in a letter to me dated February 26, 1916, he says: "*Kritosaurus navajovius* came from the upper part of what is designated by Bauer as the Kirtland formation." At the time he wrote the original description of this dinosaur Brown considered the Ojo Alamo formation as extending downward at least 200 feet below the Puerco-Torrejon contact, so that he assigned this specimen to that formation.

Although the type specimen was found in the Kirtland shale, a trachodont maxillary, with fragments of the skull, collected by Sinclair and Granger "a few feet above the conglomerate separating the two horizons at which dinosaur bones were found," has been identified by Brown as pertaining to *Kritosaurus navajovius*, thus demonstrating the occurrence of this genus and species in the Ojo Alamo sandstone, as now defined by Bauer.

In addition to the papillate borders of the mandibular teeth, which indicate a greater antiquity than Lance for Kritosaurus, the smaller number of vertical rows in the dental magazines also points to the same conclusion. Lambe [3] from excellent material defines the genus as follows:

> Skull large, narrow, and very deep, with highly arched nasals. The lower anterior border of the premaxillæ expanded laterally. Orbit much smaller than the lateral temporal fossa. Quadrate high, partially separated from the jugal by a small quadratojugal. Mandible robust. Predentary expanded laterally and deflected in the hinder half, and posteriorly bifurcated below at the midline. Neural spines of the anterior dorsal vertebræ long. Ischia not expanded distally. Body covered with small, polygonal, nonimbricating, tuberculate scales of rather uniform size.

In figure 28 is shown a lateral view of an anterior dorsal vertebra of a large trachodont dinosaur, provisionally identified as pertaining to the genus Kritosaurus. The great height

[1] Lambe, L. M., On *Gryposaurus notabilis*, a new genus and species of trachodont dinosaur from the Belly River formation of Alberta, with a description of the skull of *Chasmosaurus belli:* Ottawa Naturalist, vol. 27, pp. 145-149, pl. 18, February, 1914.

[2] Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297-316, June, 1914.

[3] Op. cit., pp. 145-146.

of the neural spine, the relatively small size of the centrum, the weakness of the neural arch, with broad, oval neural canal, and the anterior zygapophyses close together and lower than the posterior zygapophyses, are all features in close accord with the anterior dorsals of the type specimen of Hypacrosaurus, from the Edmonton and Two Medicine formations. The above-stated combination of characters at once distinguishes this vertebra from all known Lance trachodonts, but as both Lambe

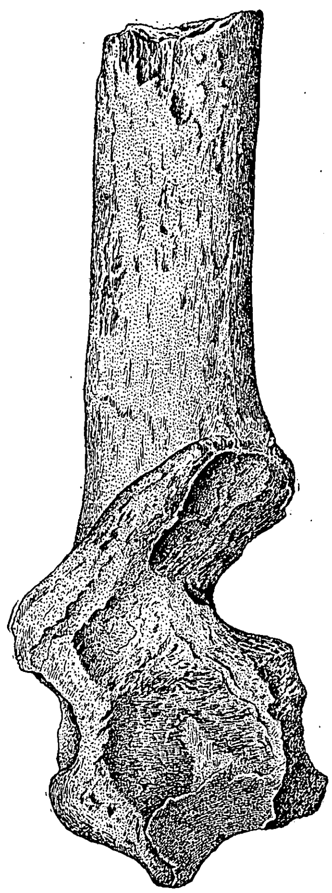


FIGURE 28.—Anterior dorsal vertebra of Kritosaurus? sp., No. 8354, U. S. N. M. About one-fourth natural size.

and Brown have described Kritosaurus as having tall spines on the anterior dorsals, it can with greater propriety be referred to that genus until such time as the discovery of undoubted remains of Hypacrosaurus show its presence in the Kirtland shale.

The only important character wherein this vertebra differs from the type of Hypacrosaurus is the lack of an opening in the thin plate which descends from a point between the posterior zygapophyses to the upper median border of the neural canal. This vertebra was associated with a number of dorsal and caudal vertebral centra, a scapula (see Pl. LXXIII, fig. 2), the proximal half of a femur, portions of two ribs, and fragmentary portions of other bones. A small trachodont femur in this same lot shows that more than one individual is represented by this collection, so it can not be positively asserted that all the bones enumerated above pertain to a single individual.

These bones were collected by Messrs. Bauer and Reeside "2 miles northwest of Ojo Alamo store; in an arroyo north of Ojo Alamo Arroyo, at a horizon 25 feet below the upper conglomerate of Sinclair and Granger [that is, in the Kirtland shale]. There is no lower conglomerate here." (See locality 60, section F, Pl. LXIV.)

Other trachodont remains.

Specimens sufficiently characteristic to be identified as pertaining to the Trachodontidæ were found by the Bauer party in the localities described in the following paragraphs. The localities are indicated by numbers on the map (Pl. LXIV).

"Canyon Ojo Amarillo, 2 miles east of Chaco River, 10 miles south of San Juan River" (locality 14, section B). Fruitland formation. A pair of maxillæ containing badly shattered teeth. In the better-preserved maxillary there are 42 vertical rows of teeth, a feature that would of itself serve to distinguish this specimen from all known Lance trachodonts, which, as shown by specimens in the United States National Museum collections, have from 52 to 57 vertical rows. The borders of the teeth are smooth, as in the upper jaw of Kritosaurus, but in the type of that genus there are 47 vertical rows, so that until the range of variation in the number of rows is determined it would be unsafe to refer the present specimen to the genus Kritosaurus. The length of the dental series is 367 millimeters, whereas in the type of *Kritosaurus navajovius* Brown it measures 410 millimeters.

"View Point, 5 miles northwest of Pina Veta China" (locality 35, section C). Kirtland shale. Small portion of the dentary of a trachodont dinosaur.

"View Point, 5 miles northwest of Pina Veta China" (locality 34, section C). Farmington sandstone member of the Kirtland shale. Distal end of a humerus and centrum of a caudal vertebra.

"About 23 miles south of Farmington, near the reservation line, 1 mile north of Brimhall Store" (locality 46, section D). Uppermost part of the Kirtland shale. Two anterior caudal vertebræ of a large individual.

"About 30 miles south of Farmington and 4 miles east of reservation line" (locality 80, section E). Lowermost part of the Kirtland shale. Phalanges and cervical vertebræ.

"About 4½ miles northwest of Ojo Alamo store, on head of Hunter Wash; 25 feet below Ojo Alamo" (locality 53, section E). Uppermost part of the Kirtland shale. Right femur of very large individual.

"About 2 miles south of Fruitland, 100 feet above the top of the Pictured Cliffs sandstone" (locality 6, section A). Fruitland formation. Centrum of a caudal vertebra.

"One mile north of west of Ojo Alamo store; 25 feet below the upper conglomerate of Sinclair and Granger. There is no lower conglomerate at this point; it is apparently consolidated with the upper" (locality 62, section F). Uppermost part of the Kirtland shale. Portion of the dentary.

"About 1½ miles southwest of Ojo Alamo store, half a mile west of wagon road; 8 feet above base of lower conglomerate of Sinclair and Granger" (locality 65, section F). Ojo Alamo sandstone. Axis with fused odontoid process. This specimen was submitted to Barnum Brown, of the American Museum of Natural History, New York, who reports: "The axis with fused odontoid process is probably trachodont, possibly Kritosaurus, but it does not agree with any of the material we have in our collections."

"One mile north of west of Ojo Alamo store, in small basin north of Ojo Alamo Arroyo; 20 feet below the conglomerate of Sinclair and Granger, lower and upper combined" (locality 62, section F). Uppermost part of the Kirtland shale. Two caudal vertebræ and portions of a pelvic bone.

"Three miles northwest of Ojo Alamo store; 40 feet below the lower conglomerate" (locality 56, section E). Uppermost part of the Kirtland shale. Portion of the right dentary.

"North side of Barrel Springs Arroyo, half a mile west of wagon road from Ojo Alamo; 10 feet above lower conglomerate" (locality 63, section F). Ojo Alamo sandstone. Fragmentary teeth.

"North side of Barrel Spring Arroyo, about 1¼ miles southwest of Ojo Alamo store; 20 feet below the lower conglomerate" (locality 66, section F). Uppermost part of the Kirtland shale. Considerable part of the dentary with fragments of teeth. The teeth have papillate borders, and it appears likely that this specimen pertains to the genus Kritosaurus.

"One mile east of Pina Vita China, about 20 feet below the conglomerate" (locality 42, section C). Upper part of the Kirtland shale. Portion of a left dentary.

Family CERATOPSIDÆ Marsh.

Monoclonius? sp.

The first Monoclonius-like remains from the Ojo Alamo sandstone were reported by Brown [1] in 1910. He says:

> The ceratopsian fragments were small sections of characteristic squamosal bones, not collected, and part of a supraorbital horn, No. 5798 of the American Museum collection. Both ends of this specimen are broken, but very little is gone from the upper end. It is 120 millimeters long, 180 millimeters in circumference at the base, and 90 millimeters in circumference at the upper end; subovate in cross section and strongly decurved near the upper end, having a greater curve on the convex than on the concave surface. It is much smaller and lacks the vascular grooves that characterize the horns of the genus Triceratops and, judging by the form and size, approaches nearest *Monoclonius recurvicornis*, of the Judith River formation, from which, however, it is distinct. *M. recurvicornis* is proportionately shorter and more robust. The squamosal fragments of another individual observed in the field were much thinner than that bone in the genus Triceratops but similarly marked by deep vascular grooves. The horn and other skull fragments were apparently from a mature animal representing a ceratopsian genus smaller than either Triceratops or Torosaurus, but the remains are too fragmentary for characterization.

The Bauer collection contains fragmentary ceratopsian remains from no less than seven localities. The better-preserved specimen (catalogue No. 7347, U. S. N. M.), from Amarillo Canyon, "10 miles south of San Juan River and 2½ miles east of Chaco River" (locality 18, section B, Pl. LXIV), "150 feet above the base of Fruitland formation," consists of the coossified atlas, axis, third and fourth cervical

[1] Brown, Barnum, The Cretaceous Ojo Alamo beds of New Mexico, with description of the new dinosaur genus Kritosaurus: Am. Mus. Nat. Hist. Bull., vol. 28, pp. 268-269, 1910.

vertebræ, considerable portions of several dorsal and caudal vertebræ, parts of two pubes, and fragments of other bones. All this material apparently pertains to one individual.

In figure 29 are shown comparative views of the anterior cervicals of *Triceratops prorsus*, *Monoclonius crassus*, and the specimen here discussed. The distinctness of the latter two from Triceratops is at once apparent, and while in a general way the anterior cervicals of the present specimen approach those of *M. crassus*, a detailed comparison shows many minor differences, sufficient to indicate at least their specific distinctness. The dorsals shown in figure 30 also indicate the close resemblance of this specimen to Monoclonius.

On account of the close resemblance of these bones I now refer the material provisionally to the genus Monoclonius. That it represents one of the so-called primitive ceratopsians there can be no question, for its relatively small size would of itself distinguish it from all known ceratopsians of the Lance formation. It is quite possible that if more perfect material were available it might be found referable to some of the other genera now known from the Judith River, Belly River, and Edmonton formations, but regardless of the uncertainty of the generic disposition of this specimen, it represents one of the primitive ceratopsians, none of which are found in deposits younger than the Edmonton.

Specimens sufficiently characteristic to be identified as pertaining to ceratopsian dinosaurs were found by the United States Geological Survey expedition of 1915 at the following localities (shown on Pl. LXIV):

"North side of Barrel Spring Arroyo, about 1 mile south of Ojo Alamo store, 1,000 feet west of wagon road; 11 feet above base of lower conglomerate of Sinclair and Granger" (locality 67, section F). Ojo Alamo sandstone. Fragments of ceratopsian teeth.

"About 4 miles west of Farmington, a quarter of a mile east of Mesa Point, and 1 mile south of San Juan River; 40 feet below the Wasatch

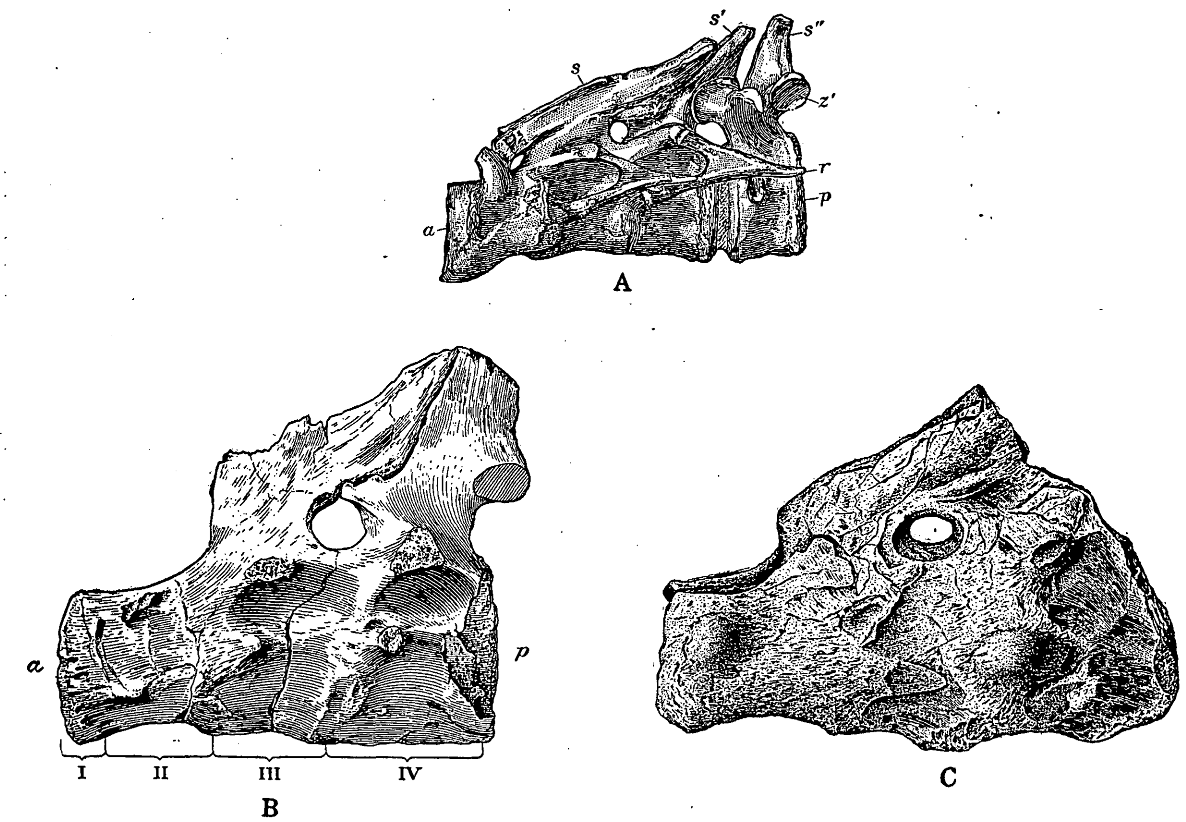


FIGURE 29.—A, Anterior cervical vertebræ of *Triceratops prorsus* Marsh, type, No. 1822, Yale Mus., one-eighth natural size. *a*, Anterior face of atlas; *p*, posterior face of fifth vertebra; *r*, rib; *s*, neural spine of axis; *s'*, neural spine of fourth cervical; *s"*, neural spine of fifth cervical; *z'*, posterior zygapophyses. (After Marsh.) B, Atlas, axis, and third and fourth cervical vertebræ of *Monoclonius crassus* Cope, No. 3998, Am. Mus. Nat. Hist., as seen from the left side, type, one-fourth natural size. *a*, Anterior end; *p*, posterior end; I, II, III, IV, cervicals. (After Hatcher.) C, Atlas, axis, and third and fourth cervical vertebræ of Monoclonius?, No. 3347, U. S. N. M., one-fifth natural size.

conglomerate" (locality 8, section A). Uppermost part of the Kirtland shale. Proximal portion of an ischium (No. 8359, U. S. N. M.) of a ceratopsian dinosaur. This bone can be clearly distinguished from the ischia of Triceratops, but I am unable to identify it with any of the other ceratopsian genera, though its small size shows it to pertain to some of the smaller members of the group.[1]

"North side of Barrel Spring Arroyo, about 1½ miles southwest of Ojo Alamo store; 1 foot above base of lower conglomerate of Sinclair and Granger" (locality 69, section F) Ojo Alamo sandstone. Fragments of the frill of a ceratopsian dinosaur, not determinable.

"North side of Barrel Spring Arroyo, 1¼ miles southeast of Ojo Alamo store; 15 feet above base of Ojo Alamo" (locality 68, section F). Ojo Alamo sandstone. Fragments of the frill of a ceratopsian dinosaur. The deep radiating vascular impressions on the upper surfaces of these fragments are very similar to those found in the genus Triceratops. Brown[2] has evidently found similarly grooved bones. He says:

> The squamosal fragments of another individual observed in the field were much thinner than that bone in Triceratops but similarly marked by deep vascular grooves. The horn and other skull fragments were apparently from a mature animal representing a ceratopsian genus smaller than either Triceratops or Torosaurus, but the remains are too fragmentary for characterization.

Similar fragments discovered in 1908 by James H. Gardner, of the United States Geological Survey, near the head of Coal Creek, 1 mile southeast of Ojo Alamo, were identified by me as pertaining to the genus Triceratops. It would now appear that this identification was in error.

"North side of Barrel Spring Arroyo, half a mile west of wagon road from Ojo Alamo; 10 feet above 'lower' conglomerate" (locality 63, section F). Ojo Alamo sandstone. Teeth of a ceratopsian dinosaur, not determinable.

[1] Since the above observations were written this specimen was sent to Mr. Barnum Brown, of the American Museum of Natural History, and he reports as follows: "The ischium is undoubtedly that of Monoclonius. It agrees in form and size with that of a skeleton collected last year from the Belly River of Alberta—*Monoclonius flexus*."

[2] Am. Mus. Nat. Hist. Bull., vol. 28, p. 269, 1910.

Family ANKYLOSAURIDÆ Brown.

The presence of armored dinosaurs in the deposits of the San Juan Basin is now shown by the discovery of a right humerus (No. 8360, U. S. N. M.) collected by J. B. Reeside, jr., "2 miles northwest of Ojo Alamo store, 20 feet below the conglomerate" (locality 59, section E). Kirtland shale.

This specimen was placed in the hands of Mr. Barnum Brown, of the American Museum of Natural History, who reports as follows:

> The humerus is that of a genus of the Ankylosauridæ. It agrees in size and form with one of our specimens from the Belly River of Alberta. I have not yet named this genus but am working on it. This genus is typical of the Belly River of Alberta and not found in the Edmonton or Lance formations.

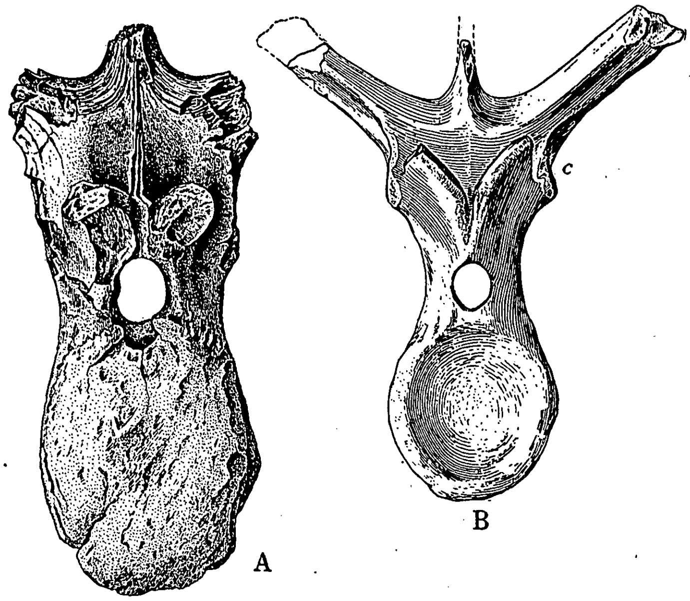


FIGURE 30.—Median dorsal vertebræ, anterior view: A, Monoclonius, No. 8347, U. S. N. M., one-fourth natural size. B, *Monoclonius crassus* Cope, No. 3998, Am. Mus. Nat. Hist., one-fourth natural size. c, Capitular. (After Hatcher.)

Suborder THEROPODA.

Family MEGALOSAURIDÆ.

Deinodon?

Plate LXXIII, figures 1 and 4.

In the collection made by Sinclair and Granger in 1913 were separate teeth which Brown[3] has provisionally identified as pertaining to the genus Deinodon.

The Bauer collection also contains detached teeth that are identical in every way with those

[3] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, p. 303, 1914.

figured by Leidy[1] as *Deinodon horridus* (see Pl. LXXIII, fig. 4), but in view of the paucity of our knowledge concerning the complete dentition of the several genera of carnivorous dinosaurs now named, and especially as the few dentitions known show so considerable a degree of differentiation of the teeth in different parts of the jaws, the provisional reference of detached teeth to a genus based on such material is in the highest degree conjectural and can serve no useful purpose. If such material were discussed under the heading "carnivorous dinosaurs" quite as much information would be conveyed to the reader and the discussion would perhaps be less misleading.

Specimens like these have no value for correlation, as similar teeth are found in the Judith River, Belly River, Two Medicine, and Lance formations.

A list of localities and horizons where detached teeth of carnivorous dinosaurs were found is given below:

Five miles west of Pina Veta China; in Farmington sandstone member of Kirtland shale, 100 feet above its base (locality 47, section D, Pl. LXIV).

A single tooth (Pl. LXXIII, fig. 4; No. 8355, U. S. N. M.) resembling in nearly every detail the D-shaped tooth figured by Leidy.[2]

"One mile south of camp No. 6, 30 miles south of Farmington, 1 mile east of reservation; upper part of coal-bearing beds, 10 feet above highest coal" (locality 76, section E). Fruitland formation. Tooth fragments of carnivorous dinosaur.

"About 39 miles south of Farmington and 4 miles east of reservation line" (locality 80, section E). Lower part of Kirtland shale, 350 feet above base. Fragmentary teeth of carnivorous dinosaurs.

"North side of Barrel Spring Arroyo, about a mile south of Ojo Alamo store, 1,000 feet west of wagon road; about 11 feet above base of 'lower conglomerate' of Sinclair and Granger" (locality 67, section F). Ojo Alamo sandstone. Tooth of large carnivorous dinosaur.

"One mile north of west of Ojo Alamo store; 25 feet below the upper conglomerate of Sinclair and Granger. There is no lower conglomerate at this point; it is apparently consolidated with the upper" (locality 62, section F). Kirtland shale. Tooth of carnivorous dinosaur.

"Two miles northwest of Ojo Alamo store; 20 feet below the conglomerate of Sinclair and Granger" (locality 59, section E). Upper part of Kirtland shale. Median phalange of small carnivorous dinosaur; tooth of large carnivorous dinosaur.

"North side of Barrel Spring Arroyo, half a mile west of wagon road from Ojo Alamo; 10 feet above 'lower' conglomerate" (locality 63, section F). Ojo Alamo sandstone. Teeth of carnivorous dinosaurs.

In Plate LXXIII, figure 1, is shown a left dentary (No. 8346, U. S. N. M.) of a carnivorous dinosaur collected by J. B. Reeside, jr., "28 miles south of San Juan River and about 12 miles east of the Navajo Reservation line at the head of Hunter Wash" (locality 60, section F, Pl. LXIV), from the upper part of the Kirtland shale. In this bone are sockets for 13 large teeth, but except a germ tooth in the ninth alveolus from the front all the others have been lost. This germ tooth is compressed laterally, lenticular in section in the upper portion, and serrate on both borders. It is indistinguishable from some of the detached teeth found at other localities by the Bauer party. The 13 alveoli occupy a space about 354 millimeters long. At the third alveolus the dentary on the external side had a depth of 93 millimeters; at the eleventh alveolus it is 110 millimeters deep. As in the other Cretaceous Theropoda, the alveolar partitions expand internally into interdental rugosæ.

In the number of tooth sockets this jaw agrees with *Dynamosaurus imperosus* Osborn,[3] but in the general form of the dentary, particularly the contour of the anterior end, it approaches Albertosaurus[4] (Dryptosaurus) most nearly, but as the dentary of Albertosaurus has sockets for 15 teeth the presence of 13 in this individual would appear to show its distinctness.

It is quite possible that this dentary pertains to the genus Deinodon, but that can not be determined at this time because the dentary of that genus is unknown. The identification of this specimen must therefore await the discovery of additional material.

[1] Leidy, Joseph, Extinct Vertebrata from the Judith River and Great Lignite formation of Nebraska: Am. Philos. Soc. Trans., vol. 11, pl. 9, figs. 41–45, 1859.

[2] Idem, figs. 41, 42.

[3] Osborn, H. F., Tyrannosaurus and other Cretaceous carnivorous dinosaurs: Am. Mus. Nat. Hist. Bull., vol. 21, p. 263, 1905.

[4] Idem, p. 265.

Order CROCODILIA.

The presence of crocodiles in the San Juan Basin is shown by numerous shed teeth in the collection made by the Bauer party in 1915. Differences observed in these teeth would appear to indicate the presence of two or more species, but it is quite impossible to identify species or even genera from these simple conical teeth. Similar teeth have been frequently found in the Judith River, Belly River, Two Medicine, and Lance formations, and until identifiable specimens are found these detached teeth can have no value for correlative purposes.

Crocodile remains were collected at the localities shown in Plate LXIV and described below.

"One mile south of camp No. 6, 30 miles south of Farmington, 1 mile east of reservation" (locality 76, section E). Fruitland formation. Teeth.

"About 30 miles south of Farmington and 4 miles east of reservation line" (locality 80, section E). Lower part of Kirtland shale. Teeth and limb bone.

"North side of Barrel Spring Arroyo, about a mile south of Ojo Alamo store" (locality 67, section F). Ojo Alamo sandstone. Teeth and dermal scute.

"One mile north of west of Ojo Alamo store" (locality 63, section F). Ojo Alamo sandstone. Tooth.

Family ALLIGATORIDÆ.

Brachychampsa sp.

The genus Brachychampsa[1] is based on a well-preserved skull containing teeth, from the Lance formation as exposed on Hell Creek, Mont.

In the Bauer collection are detached teeth which I am unable to distinguish from those of the type specimen of Brachychampsa and which in all probability should be referred to that genus. The United States National Museum collections contain similar teeth from the Judith River and Lance formations, so that in the present state of our knowledge these detached teeth have no value as formation indicators.

Brachychampsa teeth have been found in two localities in the San Juan Basin, both in the Kirtland shale—"30 miles south of Farmington and 4 miles east of the reservation line," and "30 miles south of San Juan River and 5½ miles east of the reservation line, on a trail up Hunter Arroyo" (locality 72, section E, Pl. LXIV).

Order CHELONIA.

Altogether eight genera and nine species of fossil turtles are now recognized from the Ojo Alamo sandstone and the immediately underlying formations. Of the eight recognized species only one has been found elsewhere, the others being based on specimens obtained from these deposits. Unfortunately, at least half of these species are founded on very fragmentary specimens, for the most part fragments of the carapace.

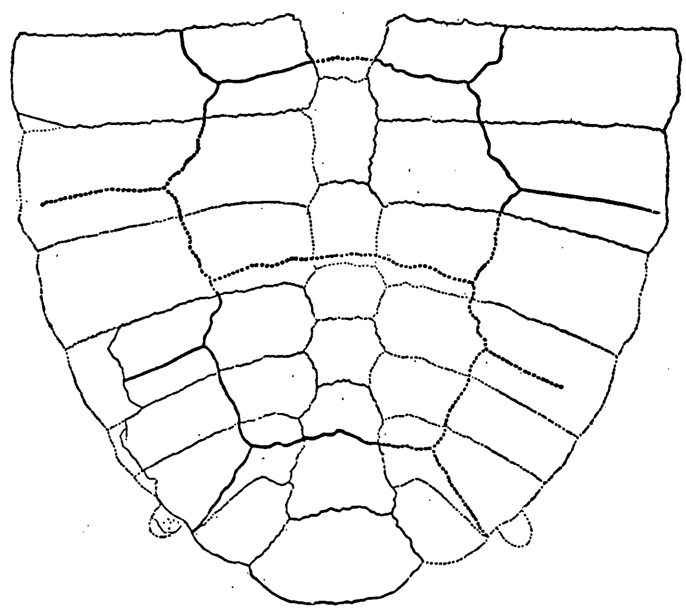


FIGURE 31.—Carapace of *Neurankylus eximius* Lambe. Type. Museum of the Canada Geological Survey, Ottawa. One-third natural size. (After Lambe.)

Family PLEUROSTERNIDÆ Cope.

Genus NEURANKYLUS Lambe.

The genus Neurankylus was established by Lambe[2] in 1902 upon a somewhat fragmentary specimen from the Belly River formation as exposed on Red Deer River in the Province of Alberta, Canada. The type consists of the posterior two-thirds of a carapace, from which all the peripheral bones are missing. (See fig. 31.)

[1] Gilmore, C. W., A new fossil alligator from the Hell Creek beds of Montana: U. S. Nat. Mus. Proc., vol. 41, pp. 297-302, pls. 26-27, 1911.

[2] Lambe, L. M., On the vertebrata of the Mid-Cretaceous of the Northwest Territory: Contr. Canadian Paleontology, vol. 3, pt. 2, pp. 42, 43, text fig. 7, 1902.

The great width of the vertebral scutes, the presence of a ninth pair of costals, and a greatly enlarged eighth neural were considered a combination of characters sufficient to separate it generically from all described forms. Its family affinities were thought by Lambe to be with the Chelydridæ.

In 1908 Hay[1] removed this genus to the Baenidæ and defined the genus Neurankylus as follows:

> A genus of uncertain position and known only from a portion of the carapace of the type species. Eighth neural large, followed by an expanded suprapygal. In the type a ninth pair of costal bones. The vertebral scutes nearly twice as wide as long.

The presence of an extra pair of costals in the type of *Neurankylus eximius* is considered by Hay an individual variation and therefore not of classificatory value. The large size of the eighth neural, as suggested by Lambe and as now shown by the type of *Neurankylus baueri*, was brought about by the coalescence of the last neural with the suprapygal and on that account can not be considered a diagnostic character. It will thus be observed that so far as the type species is concerned the great width of the vertebral scutes constitutes the principal character for distinguishing this genus.

The specimen discussed below is, on account of the close resemblance of its vertebrals to those of *Neurankylus eximius*, provisionally referred to the genus Neurankylus. The discovery of better-preserved specimens in the Belly River formation may possibly show the generic distinctness of these individuals, but in the light of our present knowledge the evidence points to their being congeneric.

The genus Neurankylus may now be defined as follows: Carapace depressed; neurals with interrupted, obtuse, dorsal carina; mesoplastrals meeting narrow on the midline; inguinal buttresses barely reaching borders of fifth and sixth costals; vertebrals very broad as compared to their length.

The close resemblance of the present specimen to the genus Glyptops shows it to be a true member of the Pleurosternidæ, so that now this family is represented in North America by the genera Glyptops and Neurankylus.

[1] Hay, O. P., The fossil turtles of North America: Carnegie Inst. Washington Pub. 75, pp. 93, 94, text fig. 90, 1908.

Neurankylus baueri Gilmore, n. sp.

Plates LXXIV, LXXV; text figures 32 and 33.

Type: No. 8344, U. S. N. M., consisting of a complete carapace and plastron. Collected by C. Max Bauer and J. B. Reeside, jr., 1915.

Locality: "About 30 miles south of Farmington and 4 miles east of reservation line," San Juan Basin, San Juan County, N. Mex. (Locality 80, section E, Pl. LXIV.)

Horizon: Lower part of the Kirtland shale.

The specimen on which this species is founded is a beautifully preserved shell, lacking only some minor fragments. Dorsoventrally it is considerably depressed, but the outlines of the carapace and plastron are little distorted and give a good idea of the form of the living animal. In its general form the carapace is broadly oval, broad behind, with scalloped borders posterior to the inguinal notches, and regularly rounded in front with the exception of a slight median emargination. Even aside from effect of the vertical crushing the shell was still depressed.

At the center the carapace has a greatest length of 560 millimeters. Its greatest width is 480 millimeters. The entire border anterior to the inguinal notches is thickened and rounded, but posteriorly it thins out to an acute edge. All the peripheral bones flare upward. This upward inclination is most pronounced along the sides, where it forms a wide, shallow gutter, much as in *Glyptops plicatulus* (Cope). (See fig. 32.)

Delicate striations cross the sutures at right angles, and faint scutal growth markings on the marginals constitute the ornamentation of the carapace.

On the median line, within the third, fourth, and fifth vertebrals, are short, obtuse elevations, but elsewhere there is no indication of any carina. The sulci are narrow and moderately impressed. The sutures have all coalesced, but by means of the transverse lines mentioned above the courses of nearly all of them can be accurately traced.

There are eight neural plates. All except the sixth, which is octagonal, and the seventh, which is subrectangular, are hexagonal, with the widest end forward. Their principal dimensions are as follows:

Dimensions of neurals in Neurankylus baueri, in millimeters.

No.	Length.	Width.	No.	Length.	Width.
1	60	46	5	50	40
2	48	40	6	55	52
3	55.5	42	7	26	30
4	56	45	8	30	43

The pygal has a greatest length at the center of 40 millimeters, and a greatest width on the free border of 60 millimeters.

There are eight pairs of costals, there being no evidence of a ninth pair, as found by Lambe[1] in the type specimen of *Neurankylus eximius*. They gradually decrease in width from front to back, only the eighth being relatively wider than the one immediately preceding it.

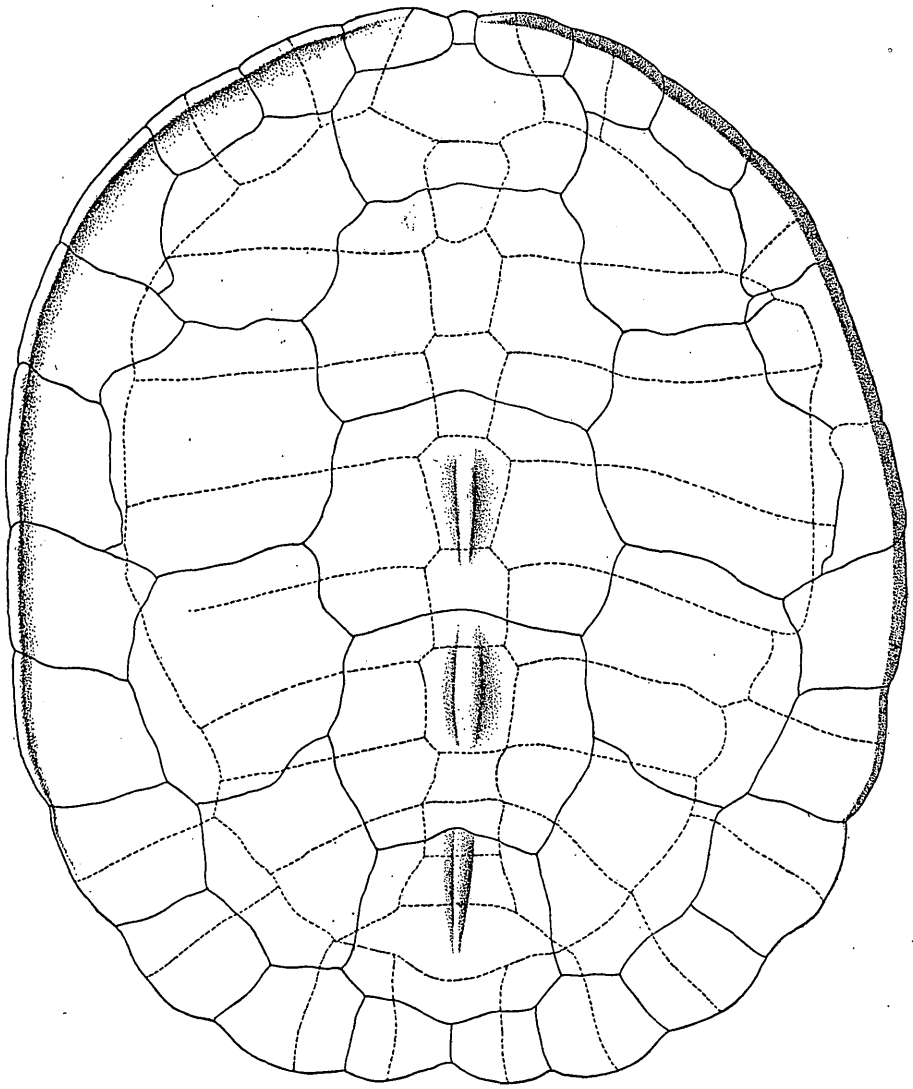


FIGURE 32.—Carapace of *Neurankylus baueri* Gilmore, n. sp. Type, No. 8344, U. S. N. M. One-fourth natural size.

The nuchal is 73 millimeters long, 52 millimeters wide on the free border, and has a maximum width of 92 millimeters.

The first suprapygal has the form of a trapezoid, being 27 millimeters long and 64 millimeters wide. The second suprapygal is lozenge-shaped, 40 millimeters long and 120 millimeters wide.

The border of the carapace is made up of 11 pairs of peripheral bones, and all excepting the third, fourth, and sixth extend entirely mesiad of the costoperipheral sulcus. The first has a height of 60 millimeters; the third, 59 millimeters; the fifth 64 millimeters; the

[1] Lambe, L. M., On Vertebrata of the Mid-Cretaceous of the Northwest Territory, pt. 2: Contr. Canadian Paleontology, vol. 3, p. 42, fig. 7, 1902.

seventh, 71 millimeters; the ninth 84 millimeters; the eleventh, 70 millimeters.

The vertebral scutes are very broad compared to their length, as in *Neurankylus eximius* Lambe. These scutes, however, are relatively longer than in the species just mentioned. Their sides are strongly bracket shaped.

The nuchal scute is small and subrectangular in outline, and its greatest diameter is anteroposterior. Its length is 19 millimeters; its width on the free border 14 millimeters. The supracaudal scute is divided, as in Hadrianus.

On account of the great breadth of the vertebrals and the considerable mesiad extension

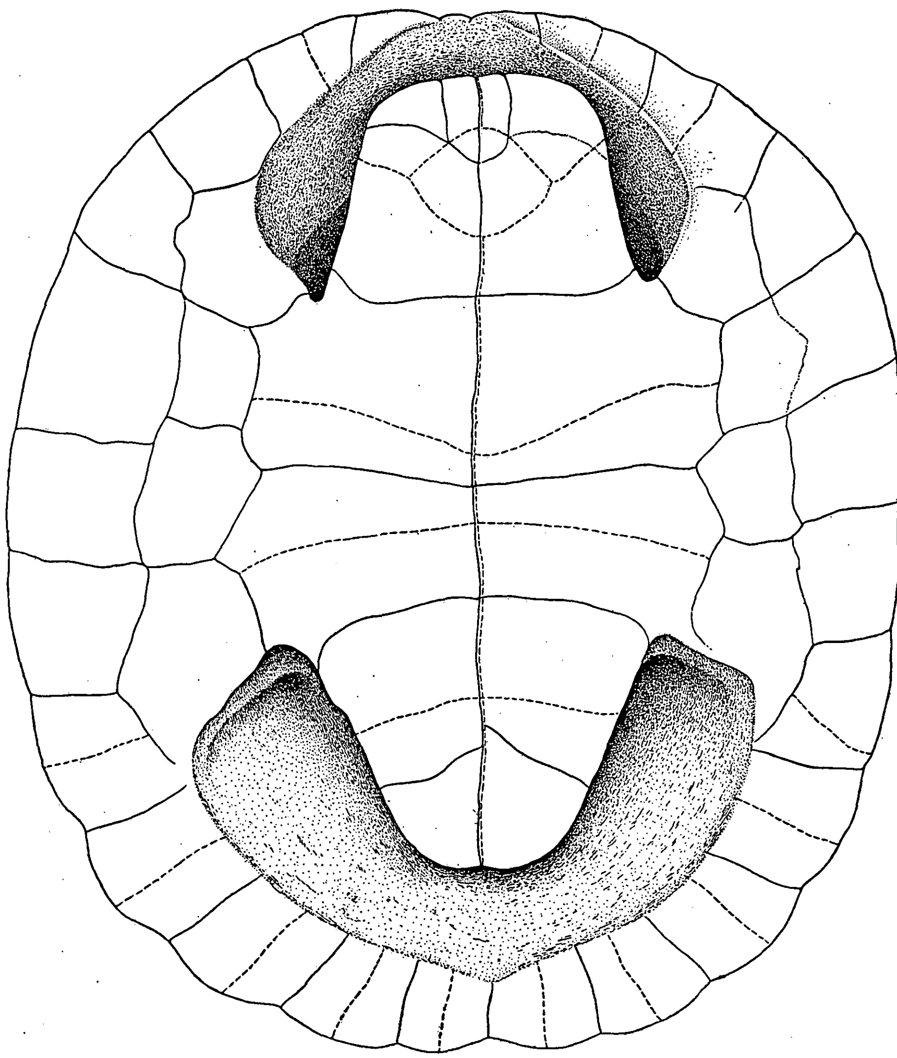


FIGURE 33.—Plastron of *Neurankylus baueri* Gilmore, n. sp. Type, No. 8344, U. S. N. M. One-fourth natural size.

of the inguinals the costal scutes have the rather unusual proportion of being as broad as long.

The marginal scutes alternate with the peripheral bones. The fourth, fifth, and seventh extend inward across the costoperipheral suture, but all the others are external to this suture.

The plastron (Pl. LXXV; text fig. 33) has a total length of 416 millimeters. It is broad in front, as in other members of the Pleuro-

The principal measurements of these scutes are given below.

Dimensions of scutes of Neurankylus baueri, in millimeters.

No.	Length.	Width in front.	Greatest width.
1	81	110	133
2	106	93	165
3	110	125	167
4	114	117	140
5	108	82	117

sternidæ. The posterior lobe is tapering; the narrowed end truncated, with a very slight median emargination. The concavity of the plastron would indicate this individual to be a male.

The anterior lobe is 111 millimeters long and at the base 168 millimeters wide. At the gular-humeral sulcus it measures 123 millimeters in width. The front of the lobe has a thickened, rounded margin. At the center it measures 12 millimeters in thickness. The posterior lobe at the center is 122 millimeters long and 185 millimeters wide at the base. The lateral borders converge rapidly from the inguinal notch backward to the truncated posterior end.

The bridge has a width of 195 millimeters.

The epiplastra meet on the midline by a suture 30 millimeters long; the hypoplastra for 120 millimeters, the mesoplastra for 30 millimeters, the hypoplastra for 95 millimeters, and the xiphiplastra for 88 millimeters.

The buttresses are rather narrow, as in other Pleurosternidæ. The axillary extends well upward toward the vertebræ on the under side of the first costal. The inguinal buttress rises little if at all above the costoperipheral suture.

The intergular scutes meet on the midline for 40 millimeters, and they overlap the entoplastron. The gulars do not meet on the midline or overlap the entoplastron. The humerals meet on the midline for a distance of 79 millimeters, the pectorals for 100 millimeters, the abdominals for 60 millimeters, the femorals for 58 millimeters, and the anals for 64 millimeters.

There are four inframarginal scutes.

Family BAENIDÆ Cope.

Baena nodosa Gilmore, n. sp.

Plate LXXVI; text figures 34 and 35.

Type: No. 8345, U. S. N. M.; consists of a nearly complete carapace and plastron. The principal parts missing are portions of the posterior border at either side of the middle. Collected by J. B. Reeside, jr., and John Brittain, September 8, 1915.

Locality: "Two miles northwest of Ojo Alamo store," San Juan County, N. Mex. (See locality 60, section F, Pl. LXIV.)

Horizon: Kirtland shale.

The very rough surface ornamentation of the carapace of the type specimen is especially characteristic of this species, and this feature alone will serve to distinguish it from all other described forms. The ornamentation consists of a series of rounded nodelike elevations of irregular shapes and unequal sizes placed without definite arrangement. Along the central portion of the carapace these node swellings are elongate anteroposteriorly, with narrow longitudinal grooves between. Interspersed here and there among the elongate nodes are short, rounded elevations. Lateral to the vertebral areas the nodes are more widely scattered, and the valleys between them are wider and deeper. The peripheral surfaces are comparatively smooth.

In form the anterior end of the carapace is obtusely pointed. Proceeding posteriorly the lateral borders are divergent to a point posterior to the inguinal notches, where they round into the wide, truncated posterior end. This end has a decided median emargination, at each side of which the border is scalloped. The number of these scallops can not be determined in the present specimen. The sulci are narrow and shallowly impressed, but most of those of the carapace can be clearly traced. The sutures, however, have been obliterated through coossification, and are to be observed only between a few of the costals. (See fig. 34.)

The greatest length of the carapace at the center is 354 millimeters; the greatest width, which is posterior to the inguinal notches, is 344 millimeters. The depth of the shell at the center is 80 millimeters, but in life this measurement was considerably greater.

The nuchal scute, relatively of large size, has a length of 23 millimeters and a width on the free border of 19 millimeters; its greatest width is 27 millimeters.

The vertebral scutes when compared with those of other species of the genus are relatively narrow. As in *Baena hatcheri* Hay, from the Lance formation, an accessory lateral scute is cut off from each side of the first vertebral, thus greatly reducing it in size. But *B. nodosa* differs from *B. hatcheri* Hay in having a large nuchal scute that takes the place of the extremely small first vertebral and forms scutellæ as in *B. hatcheri*.

The sides of the vertebrals are but little enlarged laterally at their centers. Their principal dimensions are given in the table.

Dimensions of vertebrals of Baena nodosa, in millimeters.

Number.	Length.	Width in front.	Greatest width.
1	50	24	62
2	82	54	74
3	81	66	80
4	76	61	71
5	54	49	93

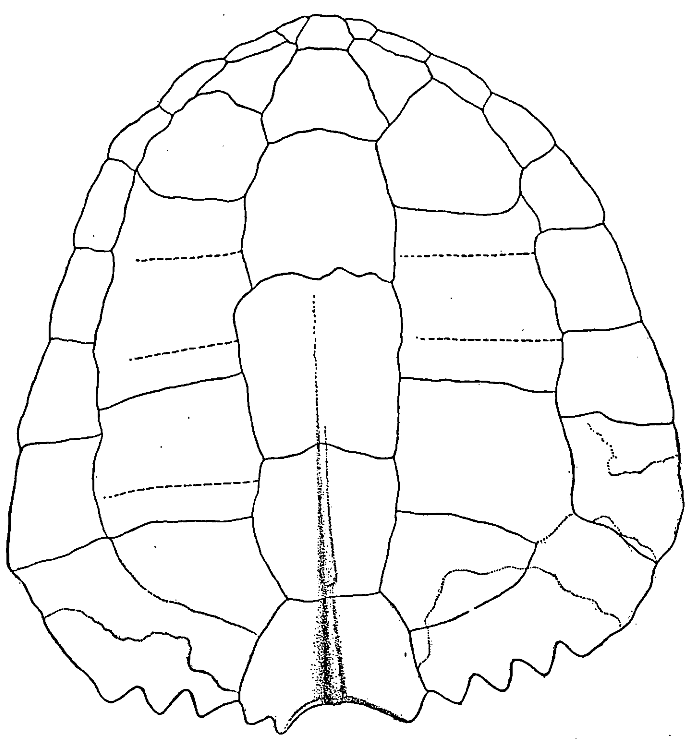


FIGURE 34.—Carapace of *Baena nodosa* Gilmore, n. sp. Type, No. 8345, U. S. N. M. About one-fourth natural size.

The triangular supernumerary lateral scutes are each 44 millimeters anteroposteriorly and 54 millimeters transversely. The nuchal has on each side a small triangular marginal scute with a free border 16 millimeters in length. The second marginal is extremely narrow fore and aft (11 millimeters) but has a length on the free border of 27 millimeters. The third marginal extends back from the border 18 millimeters; the fourth 26 millimeters; the seventh 62 millimeters; the eighth 59 millimeters. The number of marginals can not be determined in this specimen. As in other species of this genus there is no supracaudal scute, the fifth vertebral coming to the posterior margin.

The emargination on the posterior border is 59 millimeters wide. At its center the bone is thickened to 12 millimeters, thus forming an obtuse median ridge that continues well forward toward the middle of the fifth vertebral scute.

The plastron (fig. 35) is comparatively smooth, having only a finely granulated surface. The concave nature of the plastron would indicate this individual to be a male.

The plastron has a greatest length of 323 millimeters. The sides of the plastron, beginning with the bridges, rise upward and outward clear to the margin of the shell, so that the margin stands considerably above the level of the plastron.

The anterior lobe is 81 millimeters long and 113 millimeters wide at the base. The width diminishes gradually to the gular-humeral sulcus, where it measures 71 millimeters transversely. It is slightly notched at this point and again where the gular-intergular sulcus crosses the margin. The anterior border is slightly emarginate.

The limits of the entoplastron can not be traced. The bridge is 149 millimeters wide.

The posterior lobe is 89 millimeters long and 132 millimeters wide at the base. The posterior end is truncated and has a shallow but broad emarginated border. At the femeroanal sulcus the sides of the lobe are slightly constricted.

By means of the striations on the bones the limits of the mesoplastrals can be accurately determined. They meet rather broadly on the midline for a distance of 36 millimeters and expand toward the outer margins of the shell. All the other sutures are largely obliterated on account of the complete coossification or fusion of the bones.

There are distinct gulars and intergulars, all of about the same shape and size, as in *Baena hatcheri* Hay. These scutes all start from a common point at the midline. The intergulars meet at the midline for a distance of 29 millimeters; the humerals for 61 millimeters; the pectorals for 61 millimeters; the anals for 47 millimeters. The median longitudinal sulcus appears to follow a tortuous course, as in several other species of the genus.

On the bridge there are four large inframarginal scutes. These appear to lie principally on the plastral bones, though extending over on to the peripherals.

This species is distinguished from all others in the rough, nodelike ornamentation of the carapace, in the triangular shape of the shell, and in having the greatest breadth posterior to the inguinal notches.

Thescelus rapiens Hay.

Text figure 36.

Thescelus rapiens Hay, The fossil turtles of North America: Carnegie Inst. Washington Pub. 75, pp. 97–98, text figs. 91–92, 1908.

Sinclair and Granger, Am. Mus. Nat. Hist. Bull., vol. 33, p. 303, 1914.

The original description is as follows:

This species is represented by a single shell, which was collected from "Laramie" deposits [1] at Ojo Alamo, San Juan County, N. Mex., in 1904, by Mr. Barnum Brown, of the American Museum of Natural History. The catalogue number of the specimen is 6066. The shell has been damaged considerably by weathering and lacks a portion of the carapace in the nuchal region, some portions of the right costals, most of the peripherals, the front of the plastron, and the rear of the xiphiplastrals.

The length of the carapace must have been close to 400 millimeters; the width about 375 millimeters. Apparently the shell was considerably depressed. The front of the carapace over the neck was excavated, but not so deeply as in *T. insiliens*. The area occupied by the vertebral scutes presents a broad, shallow, longitudinal channel; but in this, over the neural bones, there is a low ridge. The free borders of the anterior peripherals are rather obtuse.

The sutures of the shell are obliterated, but a few of them may be traced by the fine striations which cross them. So far as they can be made out, they are shown in the diagrammatic figures. The scutal areas are distinctly marked on the shell. They present various irregularities. The vertebrals [fig. 36, A] are broader than long; their dimensions are shown in the table below:

Dimensions of vertebrals of Thescelus rapiens, in millimeters.

No.	Length.	Width.
1	50±	82±
2	75	92
3	81	92
4	61	92
5	....	86

On the left side there is a supernumerary costal scute. This has been cut off, mostly from the first costal proper but to some extent from the second marginal. The fourth marginal shown on the left side has a height of 57 millimeters, rising somewhat on the costals.

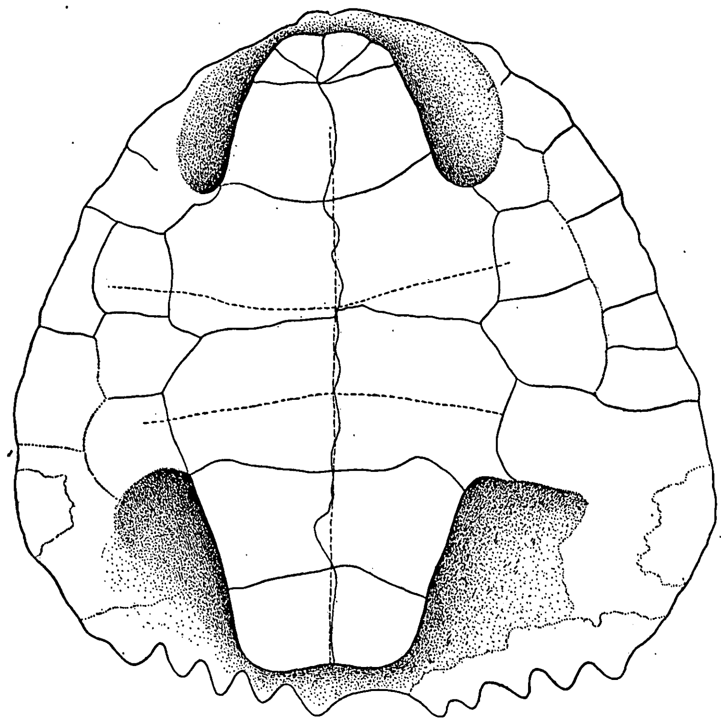


FIGURE 35.—Plastron of *Baena nodosa* Gilmore, n. sp. Type, No. 8345. U. S. N. M. About one-fourth natural size.

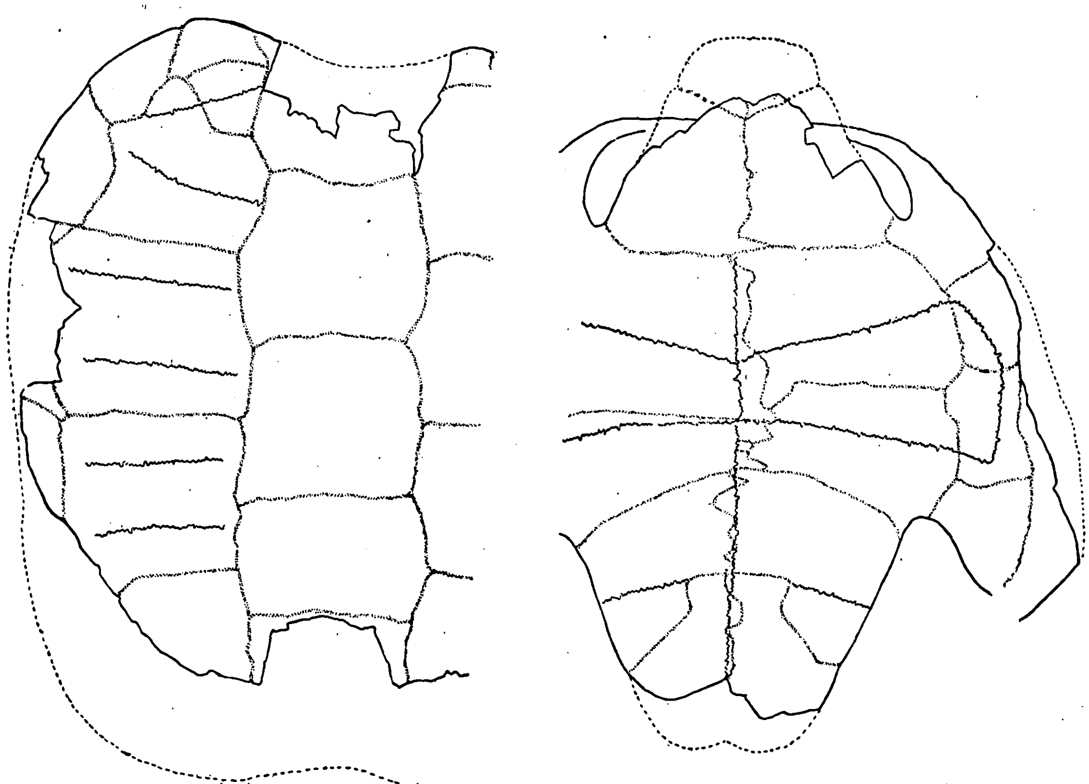
The plastron [fig. 36, B] is large. From a low ridge which joins the free border of the front lobe with that of the hinder lobe the bridges ascend at an angle with the remainder of the plastron. The axillary notch is far forward, falling about 55 millimeters behind the front of the carapace. The opening for the head and legs is thus considerably restricted. The front lobe extended evidently much beyond the front of the carapace. Its length can not be determined. The width ot the base is 150 millimeters. The bridge is 167 millimeters wide. The length of the hinder lobe was approximately 100 millimeters; the width at the base is 165 millimeters. It narrows rather rapidly backward, so that at the femoroanal sulcus the width is 104 millimeters.

There are at present large mesoplastra, the boundaries of which can be pretty satisfactorily determined. These

[1] In a letter to me dated February 26, 1916, Mr. Brown says: "*Thescelus rapiens* came from the lower conglomerate just below the old Indian trading store in Ojo Alamo," or from the Ojo Alamo sandstone.—C. W. G.

are about 35 millimeters wide at the midline, but they expand to about 85 millimeters at the peripherals.

The median longitudinal sulcus runs a very irregular course, and across the femorals it can not be distinguished with certainty. The humerals occupy 70 millimeters of the midline; the pectorals, about 90 millimeters; the abdominals, about 35 millimeters; the femorals, about 52 millimeters. The femoroanal sulcus runs far forward from its starting point on the border of the plastron. Probably on account of weathering the sculpture of the carapace is nearly obliterated, appearing only in a few spots. On the plastron it is more distinct. It appears to have resembled that of *T. insiliens* and consists of narrow and low ridges and tubercules. Some traces are observed of the ridges due to the growth of the scutes.



A B

FIGURE 36.— *Thescelus rapiens* Hay. A, Carapace; B, plastron. Type, No. 6066, Am. Mus. Nat. Hist. About one-sixth natural size. (After Hay.)

This species differs from *T. insiliens* in having the nuchal less deeply excavated, in having a median depression along the back, and in having the hinder lobe of the plastron more rapidly reduced in width backward. In *T. insiliens* the bridges are considerably wider than the base of the hinder lobe.

It should be added that the type of *T. insiliens* mentioned above is from the Lance formation of Wyoming.

At the present time *T. rapiens* Hay is known only from the type specimen.

Family DERMATEMYIDÆ Gray.

Basilemys nobilis Hay.

Text figure 37.

Basilemys nobilis Hay, U. S. Nat. Mus. Proc., vol. 38, pp. 316–317, text figs. 12, 13, 1910.

The type specimen of this species, No. 6555, U. S. N. M., was collected by J. H. Gardner and J. W. Gidley at Ojo Alamo, N. Mex., in 1909. It was found below the upper conglomerate in the dinosaur-bearing deposits and "about 50 feet above the lower conglomerate"—therefore in the Ojo Alamo sandstone.

The specimen consists of many fragmentary parts of both the carapace and plastron. The best-preserved part is the border of the right side of the posterior lobe of the plastron, including a portion of the hypoplastron and a part of the xiphiplastron.

Hay's original description follows:

The right extremity of the fragment of hypoplastron reaches out to the suture with the eighth peripheral. From this suture to that between the hypoplastron and the xiphiplastron, following the curve, is 102 millimeters. Near the former suture the bone is 52 millimeters thick. From the border of the inguinal notch a wall extends backward along the border of the hinder lobe. At the hypoxiphiplastral suture this wall arises 40 millimeters above the lower surface of the plastron. From the summit of the wall the bone slopes downward rapidly and about equally on the outside and the inside of the wall. Where the slope ceases on the inner side of the wall the xiphiplastron is about 17 millimeters thick. Passing backward 40 millimeters the wall is somewhat higher, slightly steeper on the outside and overhanging on the inner side [fig. 37, A]. At a distance of 60 millimeters behind the hypoxiphiplastral suture the wall is 36 millimeters high and still more overhanging on the inner side. At the base of the wall here the thickness of the xiphiplastron is 21 millimeters. As the rear of the xiphiplastron is approached the wall becomes lower, only 25 millimeters where the fragment ends [fig. 37, B]. On the upper surface of the xiphiplastron there is a large oval scar which was occupied by the pubis.

On the lower surface of the outer extremity of the hypoplastron are seen the narrow threadlike sulci which bound the inguinal scute. This is only 25 millimeters

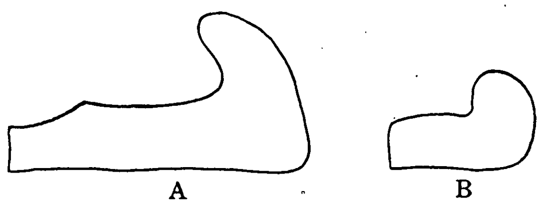


FIGURE 37.—*Basilemys nobilis* Hay. Type, No. 6555, U. S. N. M. A, Section across free border of xiphiplastron 40 millimeters behind hypoplastron; B, section across free border of xiphiplastron 115 millimeters behind hypoplastron. Both figures one-half natural size. (After Hay.)

wide, and it is thrown well out on the extremity of the bone. In *B. variolosa* this scute is much wider and extends medially to the free border of the hinder lobe. On the sloping outer face of the xiphiplastral wall, near the hinder end of the specimen, is seen a part of the femoroanal sulcus.

From *B. præclara*, described above, this species differs in at least one important respect, the inner slope of the wall around the border of the hinder lobe of the plastron. * * * It differs from *B. sinuosa* in about the same way, for in the latter the upper surface of the xiphiplastron slopes rapidly downward toward the central portion of the lobe. The writer has not at hand information regarding the same region in *B. variolosa*, but it probably does not differ in any important respect from that of *B. sinuosa*.

Hay considers the type specimen to represent an individual of "nearly the size of the type of *Basilemys variolosa* (Cope), the type of the genus, the plastron of which was about 670 millimeters long."

In the concluding paragraph of the citation given above, Hay points out wherein the present form differs from all other species of the genus, though it is at once apparent that its distinctness from the single Judith River species, *Basilemys variolosa* (Cope), has not been satisfactorily demonstrated. That it may pertain to a distinct species is quite possible, though it is perhaps significant that a fragmentary specimen of Basilemys sp. (No. 8024, U. S. N. M.) from the Two Medicine formation, which is in part equivalent to the Judith River, most closely resembles *B. nobilis* Hay. The lateral ridge on the hinder lobe of the plastron in this specimen, while not quite so prominent as in *B. nobilis*, nevertheless forms a distinct wall, as in that species, and constitutes a character which distinguishes both of these specimens from all other described forms with the possible exception of *B. variolosa.*

Adocus? lineolatus Cope.

Plate LXXVIII, figure 4.

Adocus? lineolatus Cope, U. S. Geol. and Geog. Survey Terr. Bull. [1st ser.], No. 2, p, 30, 1874; The Vertebrata of the Cretaceous formations of the West: U. S. Geol. Survey Terr. Rept., vol. 2, p. 263, pl. 6, figs. 11, 12, 1875.

Hay, Bibliography and catalogue of the fossil Vertebrata of North America: U. S. Geol. Survey Bull. 179, p. 437, 1902; The fossil turtles of North America: Carnegie Inst. Washington Pub. 75, pp. 247, 248, figs. 308, 309, 1908.

Bowen, The stratigraphy of the Montana group: U. S. Geol. Survey Prof. Paper 90, pp. 122, 123, 1915.

In the collection made by Mr. Bauer from the San Juan Basin is a fragmentary turtle (No. 8348, U. S. N. M.), consisting of the seventh peripheral from the left side, associated with a few other fragments, collected in the Fruitland formation, "1 mile south of Fruitland" (locality 4, section A, Pl. LXIV). Fortunately it can be accurately compared with the type of *Adocus vigoratus* Hay, from the same region, which also has the left seventh peripheral. The finer sculpture of the Bauer specimen, which has four to five rows of pits in a line 5 millimeters long, separates it at once from *A. vigoratus*, which has only three rows in a 5-millimeter line. This difference in sculpture is clearly shown in Plate LXXVIII, figures 3 and 4. This finer sculpture resembles closely that of *Adocus? lineolatus* Cope, to which, for the present at least, this specimen is referred.

The type of *A. lineolatus* was obtained on Bijou Creek, 40 miles east of Denver, Colo., in beds believed to be of Arapahoe age.

Knowlton[1] has stated:

Fragments that have been identified as pertaining to this species have been found by Lambe in Belly River beds of Red Deer River, Alberta, by Barnum Brown in the Lance formation on Hell Creek, Mont., and by others in the "Ceratops beds" [Lance formation] of Converse County, Wyo.

According to Hay, "Fragments of costals scarcely, if at all, to be distinguished from them [*A. lineolatus*] are found in the collection made in the Judith River region for Prof. Cope by C. H. Sternberg, in 1870."

Hatcher[2] has expressed the opinion that the reference of Lambe's specimen "may be incorrect." Hay[3] says:

It is unsafe to identify as belonging to *Adocus? lineolatus* specimens from the Judith River and Laramie beds before far better materials of the species have been collected from the type locality. It is improbable that the same species continued from the Judith River epoch to the Arapahoe epoch.

The specimen now before me shows a type of sculpture which at once distinguishes it from *Adocus vigoratus* Hay, found in the same region, a sculpture which agrees in all particulars with the description and figures of the type of *Adocus? lineolatus* Cope, so that disregarding all preconceived opinions as to what its geologic range should be, I conclude that turtles having a similar surface ornamentation of the shell lived in the Judith River, Ojo Alamo, Belly River, Arapahoe, and Lance epochs.

It is quite probable that more than one species is represented by these fragments, but until better material is found I can do no better than refer them to the described species, inadequate though that may be.

Adocus vigoratus Hay.

Plate LXXVII, figure 2; Plate LXXVIII, figure 3; text figure 38.

Adocus vigoratus Hay, U. S. Nat. Mus. Proc., vol. 38, pp. 317–318, pl. 11, fig. 3, text figs. 14–18, 1910.

The original description is given below:

The fragmentary remains which are described under the above-given name were collected September 3, 1909, by Messrs. Gardner and Gidley, at Ojo Alamo, San Juan County, New Mexico. The bones were secured below the upper bed of conglomerate [Ojo Alamo sandstone], in those beds which furnished remains of dinosaurs. The specimen bears the number 6554 of the catalogue of the U. S. National Museum.

The individual was one of considerable size, the length of the carapace having been probably 500 millimeters. One neural [fig. 38, A] present is probably the most anterior one. It is narrowed in front, notched behind, and crossed by the sulcus that passed probably between the first and the second vertebral scutes. The length is 68 millimeters along the midline; the width is 40 millimeters. The anterior end was about 6 millimeters thick; the posterior, 10 millimeters. Figure 38, B, represents the form of the first left peripheral, while figure 38, C, presents a section from the free border to the border that articulated with the first costal. The bone is about 53 millimeters wide along the anterior border and 67 millimeters high. Its greatest thickness is 19 millimeters, and this is the same where the bone joined the nuchal and where it joined the second peripheral. The free border is obtuse. On the upper surface are seen part of the first vertebral scute, a part of the first costal scute, and parts of the first and the second marginal scutes. The ascending plate of one of the bridge peripherals is penetrated by the extremity of a rib.

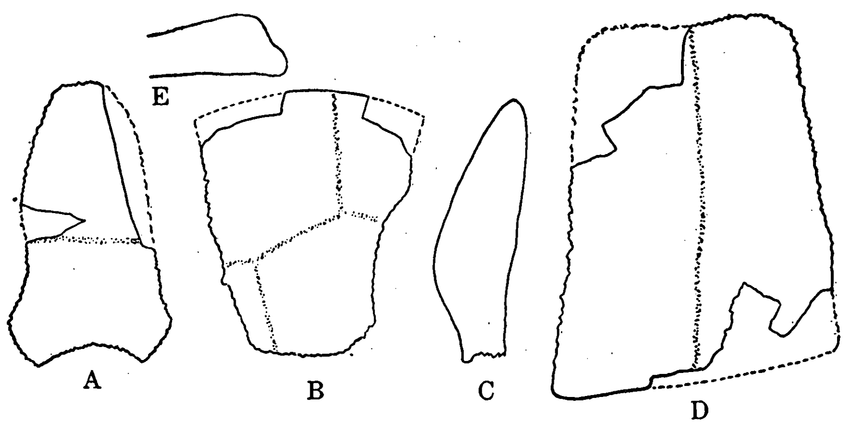


FIGURE 38.—*Adocus vigoratus* Hay. Type, No. 6554, U. S. N. M. A, First neural; B, first left peripheral; C, section across first left peripheral, the upper surface toward right; D, left seventh peripheral; E, section across free border of base of hinder lobe. All figures about one-half natural size. (After Hay.)

[1] Knowlton, F. H., Remarks on the fossil turtles accredited to the Judith River formation: Washington Acad. Sci. Proc., vol. 13, p. 57, 1911.

[2] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, p. 76, 1905.

[3] Hay, O. P., The fossil turtles of North America: Carnegie Inst. Washington Pub. 75, p. 248, 1908.

Figure 38, D, presents a view of the left seventh peripheral. Its length near the free border is 73 millimeters; its height is 96 millimeters. The free border is subacute. The border is greatly thickened, to form a shoulder to receive the inguinal buttress of the plastron. This buttress did not rise to the lower borders of the costals. On the upper part of the inner face of the bone is a shallow groove in which lay the end of the rib of the fifth costal plate. Farther down this rib enters the bone and descends a distance of 44 millimeters from the upper border.

Of the plastron there are present a fragment of the right xiphiplastron and the portion of the hypoplastron that sends up the right inguinal buttress. Figure 38, E, represents a section taken just behind this buttress. It shows the thickness of the bone and the form of the free border at the base of the hinder lobe. The underside of the fragment shows the outer end of the abdominofemoral sulcus. The xiphiplastron is quite thin, the thickness just behind the femoroanal sulcus being only 6 millimeters. The free edge is acute. The sulcus just named is directed forward as it moves toward the midline.

The outer surfaces of all the bones, those of the plastron as well as those of the carapace, are ornamented with shallow pits arranged in more or less regular rows. The rows are directed obliquely to the sutural borders of most of the bones [Pl. LXXVII, fig. 2; Pl. LXXVIII, fig. 3]. There are three rows of pits in a line 5 millimeters long. The ridges between the pits are rounded on their summits and the cross ridges are feeble.

This species is evidently different from all of those described from the eastern region of the United States. From *A. lineolatus*, the type of which came from Colorado, the present species differs in having a coarser sculpture, three rows of pits in a 5-millimeter line, instead of four or five.

Compsemys sp.

Plate LXXVIII, figure 2.

A number of broken fragments (No. 8349, U. S. N. M.) of the upper shell of a small turtle were found by Mr. Reeside "on the north side of Barrel Spring Arroyo, half a mile west of the wagon road from Ojo Alamo, in the Ojo Alamo sandstone, 10 feet above the lower conglomerate" (locality 63, section F, Pl. LXIV). These bones are covered with small, rounded pustules that form an ornamentation very close to that of *Compsemys vafer* Hay, but as other species of this genus have a somewhat similar sculpture it would not be safe to attempt a specific determination on materials so scanty.

The discovery of these specimens is of importance, however, as recording for the first time the presence of the genus Compsemys in the Ojo Alamo sandstone.

Family PLASTOMENIDÆ Hay.

Plastomenus sp.

Plate LXXVIII, figure 1.

The genus Plastomenus is represented in the Bauer collection by the complete hypoplastral bone (No. 8350, U. S. N. M.) from the left side shown in Plate LXXVIII, figure 1. I am unable at this time to identify the bone with any described species, and on account of its very large size am inclined to the opinion that it represents a new form but do not feel justified in establishing a new species on such meager material. Its chief importance here is in being the first recognizable specimen of the genus Plastomenus found in the San Juan basin.

The specimen was collected by Mr. Bauer "5 miles northwest of Pina Veta China," in the Farmington sandstone member of the Kirtland shale (locality 33, section C, Pl. LXIV).

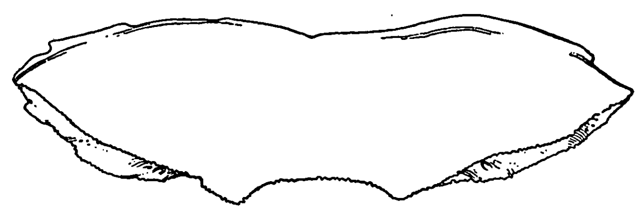


FIGURE 39.—Nuchal bone of *Aspideretes vorax* Hay. Type, No. 6140, Am. Mus. Nat. Hist. About two-fifths natural size. (After Hay.)

Family TRIONYCHIDÆ Hay.

Aspideretes vorax Hay.

Plate LXXVII, figure 3; text figure 39.

Aspideretes vorax Hay, The fossil turtles of North America: Carnegie Inst. Washington Pub. 75, pp. 496-497, text fig. 651, 1908.

The original description follows:

This species was collected from the Laramie deposits[1] near Ojo Alamo, San Juan County, N. Mex., in 1904, by Mr. Barnum Brown. The type is in the American Museum of Natural History and has the catalogue number 6140. The species is represented, as far as known, by only the nuchal bone; but this is complete. The length of the bone from side to side is 200 millimeters in a straight line, 215 millimeters over the curve. The lateral convexity is considerable and appears to have been somewhat greater than that of either *A. austerus* or *A. fontanus*, both from

[1] In response to my inquiry as to the exact geologic position of the type specimens of *Aspideretes vorax*, *A. fontanus*, and *A. austerus* Barnum Brown, in a letter of February 26, 1916, writes as follows: "The three species of Aspideretes came from clays interbedded in the sandstone of the upper part of the Ojo Alamo formation." It should be added that this determination is based on Bauer's columnar section, which Brown had before him.—C. W. G.

the same locality as this species. The width at the midline is 45 millimeters; the greatest width 55 millimeters. The greatest thickness is 15 millimeters. There is a moderate median sinus in the anterior border. This border is not clipped off at a nearly right angle with the upper surface, as in the two other species mentioned above, but is beveled down on the upper surface of the bone to a sharp edge. This beveled surface is not sculptured. The hinder border of the bone presents a median excavation, for the preneural bone. The latter bone was evidently unusually broad, the excavation having a width of at least 55 millimeters. The preneural border is thicker than that of *A. fontanus*, the thickness being 7 millimeters.

The sculpture of the bone is obscured by a layer of hard matrix; but so far as can be determined it was intermediate between *A. fontanus* and *A. austerus*, approaching more closely the latter.

Certain fragments of costals present probably belong to this species but possibly to *A. fontanus*. One of these, apparently the right sixth, is 35 millimeters wide at the neural border, 30 millimeters wide more distally, and has a thickness of 8 millimeters.

This species differs from *A. fontanus* in having the free anterior border of the nuchal beveled, the bone thicker at the preneural border, and a coarser sculpture. From *A. austerus* it differs in having a nuchal with greater anteroposterior width, the bone not so thick, and with the free anterior border beveled off instead of being clipped off at a right angle with the upper surface.

A specimen in the United States National Museum (No. 6550) has been questionably identified by Hay as pertaining to the above-named species. It consists of a portion of the nuchal and other parts of the carapace and plastral bones. In Plate LXXVII, figure 3, are shown portions of two costal plates, selected to show the character of the ornamentation.

This specimen was collected in 1909 by Messrs. Gardner and Gidley in San Juan Basin "75 feet below the Ojo Alamo sandstone, in dinosaur beds." Mr. Gidley tells me that the position as stated above was an estimate of the distance, and he is of the opinion that the specimen came from above the lower conglomerate and therefore from the Ojo Alamo sandstone.

Aspideretes austerus Hay.

Plate LXXVII, figure 1; text figures 40 and 41.

Aspideretes austerus Hay, The fossil turtles of North America: Carnegie Inst. Washington Pub. 75, pp. 495–496, text figs. 649–650, 1908.

The original description is as follows:

The fragmentary specimen on which the present species is based was collected in 1904 by Mr. Barnum Brown, from Laramie deposits [see footnote, p. 295] at Ojo Alamo, San Juan County, N. Mex. The catalogue number of the spec imen is 6068. The remains, belonging apparently to a single individual, consist of the nuchal except the central portion, part of both first costals, the greater part of a right posterior costal, probably the sixth, various fragments of costals, a piece furnishing parts of two neurals, and a considerable portion of the right hypoplastron.

The species is characterized by the very thick bones and the coarse sculpture of both the carapace and plastron.

On account of the missing middle region of the nuchal, the exact lateral extent of this bone can not be determined. It was, however, not far from 230 millimeters, being thus somewhat less than that of *A. fontanus*, just described. The greatest width is 45 millimeters, a fourth less than that of *A. fontanus*. The greatest thickness of the bone is 21 millimeters. The free anterior border is not beveled but is cut off at nearly right angles with the upper surface, like that of the species just mentioned. The thickness of this border varies from 10 millimeters toward the midline to 15 millimeters near the outer end.

The first costal is about 72 millimeters wide near the neural border, and it increases to 80 millimeters near the distal end. The free border is cut off at a nearly right

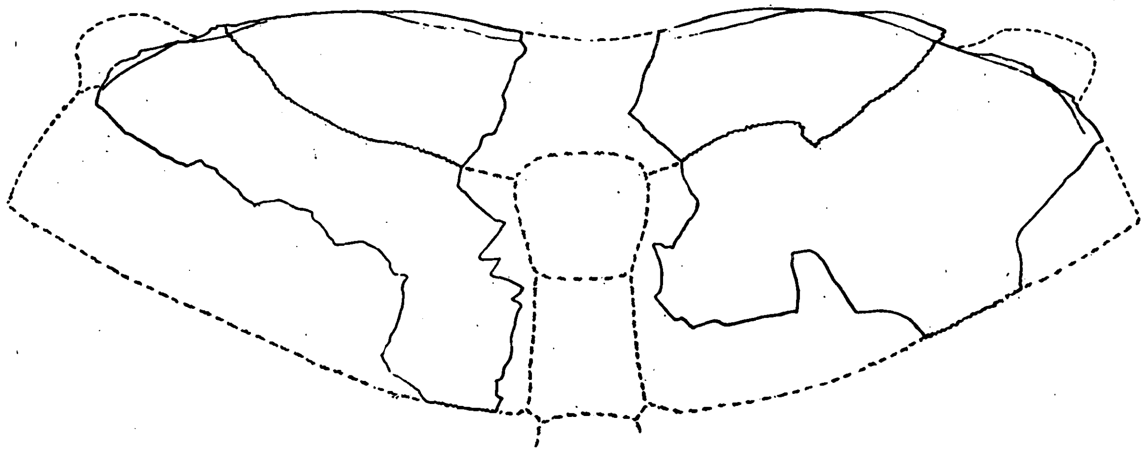


FIGURE 40.—Parts of nuchal and first costals of *Aspideretes austerus* Hay. Type, No. 6068, Am. Mus. Nat. Hist. About two-fifths natural size. (After Hay.)

angle to the upper surface. The thickness of this border is 10 millimeters or more. The hinder border of this bone is 10 millimeters thick.

The posterior, probably the sixth, costal is 25 millimeters wide 110 millimeters from the distal end, but it widens rapidly to 55 millimeters. The free border is like that of the first costal. There must have been a considerable notch between this costal and the one next behind. In thickness this costal ranges between 9 millimeters near the proximal end and 10 millimeters at the distal end.

The sculpture of the carapace is best displayed toward the free borders. It consists of abruptly sunken pits, of which there are usually five in a line 20 millimeters long. Closer to the free borders the pits are smaller. Nowhere does there appear any tendency for the formation of straight rows of pits, such as are seen on the costals of *Amyda cariosa*, of the New Mexico Wasatch. On the portions of the carapace near the midline the pits are less conspicuous. They appear to be as large, but the walls appear worn down.

The hypoplastron [fig. 41] is thick and heavy. At the suture with the hypoplastron, not far from the midline, the thickness is 13 millimeters. One border of the notch for the process of the xiphiplastron remains. This bone was articulated with the hypoplastron by a jagged suture, and it must have extended anteriorly near the midline. The outer end of the hypoplastron, near the bases of the lateral processes, is 16 millimeters thick. Evidently nearly the whole lower surface of the plastron was covered by the sculptured layer. The pits are smaller than those of the carapace, there being about seven pits in a line 20 millimeters long. Many of them coalesce to form winding furrows.

This species differs from *A. fontanus* in having a narrower nuchal, much thicker bones, and a considerably coarser sculpture. It is referred to Aspideretes provisionally.

The fragment of a costal plate (No. 8351) shown in Plate LXXVII, figure 1, is identified provisionally as pertaining to the present species. It agrees with the type specimen in being thick and heavy and especially in the character of the surface ornamentation, which is made up of abruptly sunken pits without definite arrangement in rows. It was collected by Mr. Bauer 28 miles south of San Juan River (see locality 51, section D, Pl. LXIV), "about 250 feet above the Pictured Cliffs sandstone," in the Fruitland formation.

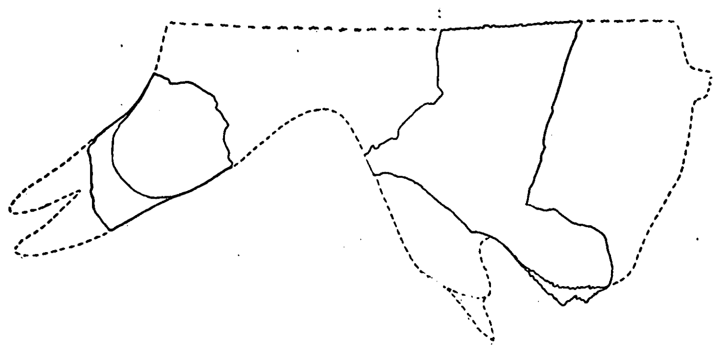


FIGURE 41.—Right hypoplastron of *Aspideretes austerus* Hay. Type, No. 6068, Am. Mus. Nat. Hist. About two-fifths natural size. (After Hay.)

Aspideretes fontanus Hay.

Text figure 42.

Aspideretes fontanus Hay, The fossil turtles of North America: Carnegie Inst. Washington Pub. 75, pp. 494–495, text fig. 648, 1908.

The original description follows:

From the Laramie beds [see footnote, p. 295] at Ojo Alamo, San Juan County, N. Mex., Mr. Barnum Brown, of the American Museum of Natural History, in 1904 brought materials belonging apparently to three species of the genus Aspideretes. Of these the present is represented by nearly the whole of the right half of the nuchal and a considerable part of the right first costal. The number of the specimen is 6070.

At no point does this piece of nuchal come to the midline; hence we can not determine the exact extent of the bone laterally. It was, however, not far from 260 millimeters. The animal was therefore one of considerable size. The inner hinder angle of the bone presents a part of the sutural border for the preneural, and from this to the outer end of the nuchal is 125 millimeters. The width of the bone where it came in contact with the preneural is 60 millimeters. The anterior border is not beveled but is cut off nearly at right angles with the upper surface.

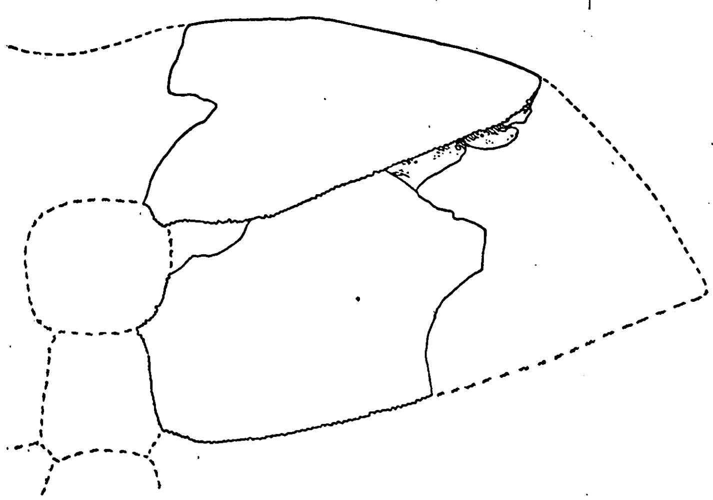


FIGURE 42.—Parts of nuchal and first right costal of *Aspideretes fontanus* Hay. Type, No 6070, Am. Mus. Nat. Hist. About two-fifths natural size. (After Hay.)

The greatest thickness, through the ridge on the lower surface, is 16 millimeters. Where it made contact with the preneural the thickness is only 4 millimeters.

The portion of the costal, the proximal half, almost certainly belongs to the same individual. At its proximal end it presents the sutural borders for the preneural and the first neural. Evidently the preneural was somewhat wider than the neural. Its length was at least 40 millimeters. The border of the costal for union with the neural is 7 millimeters thick. About the middle of the length of the hinder border of the costal the thickness is 7 millimeters.

The upper surface of the bone is incrusted with a layer of iron oxide, but so far as can be discovered the sculpture was finer than in the other two species found in that region, *A. austerus* and *A. vorax*. The few pits observed appear to be about 2.5 millimeters in diameter.

The respects in which this species differs from those just named are mentioned under their respective descriptions.

Class PISCES.

Two genera of fishes have been provisionally identified from the deposits in San Juan Basin. On account of the close similarity between them and the fish remains found in the Judith River, Belly River, Two Medicine, and Lance formations, they are of little value for correlation, although they give some indication of the character of the fish that inhabited the waters at the time these deposits were laid down.

Myledaphus sp.

Plate LXXVII, figure 4.

Myledaphus bipartitus Cope, Acad. Nat. Sci. Philadelphia Proc., 1876, p. 260.

This genus of pavement-toothed fish is represented by a considerable number of detached teeth (No. 8356, U. S. N. M.) found by Mr. Bauer's party "30 miles south of Farmington and 4 miles east of the reservation line," in the lower part of the Kirtland shale (locality 80, section E, Pl. LXIV). Teeth of this pattern are found in the Lance, Judith River, and Belly River deposits. The teeth found by the Bauer party can not be distinguished from teeth from the Judith River described by Cope as *Myledaphus bipartitus*, but it would be quite impossible to identify species from teeth of such simple pattern.

Lepisosteus sp.

Plate LXXVII, figure 5.

The genus Lepisosteus was founded on lozenge-shaped scales. Similar scales occur in the Lance, Two Medicine, Judith River, and Belly River formations, and the present specimens probably represent more than one species, but the material is too inadequate to identify species. These scales have been found in the San Juan Basin in the localities named below:

"One mile south of camp No. 6, 30 miles south of Farmington, 1 mile east of reservation; 10 feet above highest coal" (locality 76, section E, Pl. LXIV). Fruitland formation.

"About 30 miles south of Farmington and 4 miles east of reservation (locality 80, section E). Kirtland shale.

"North side of Barrel Spring Arroyo, about 1 mile south of Ojo Alamo store, 1,000 feet west of wagon road; 11 feet above base of lower conglomerate of Sinclair and Granger" (locality 67, section F). Ojo Alamo sandstone.

"About 30 miles south of San Juan River and 5½ miles east of the reservation line, on trail up Hunter Arroyo" (locality 72, section E). Kirtland shale.

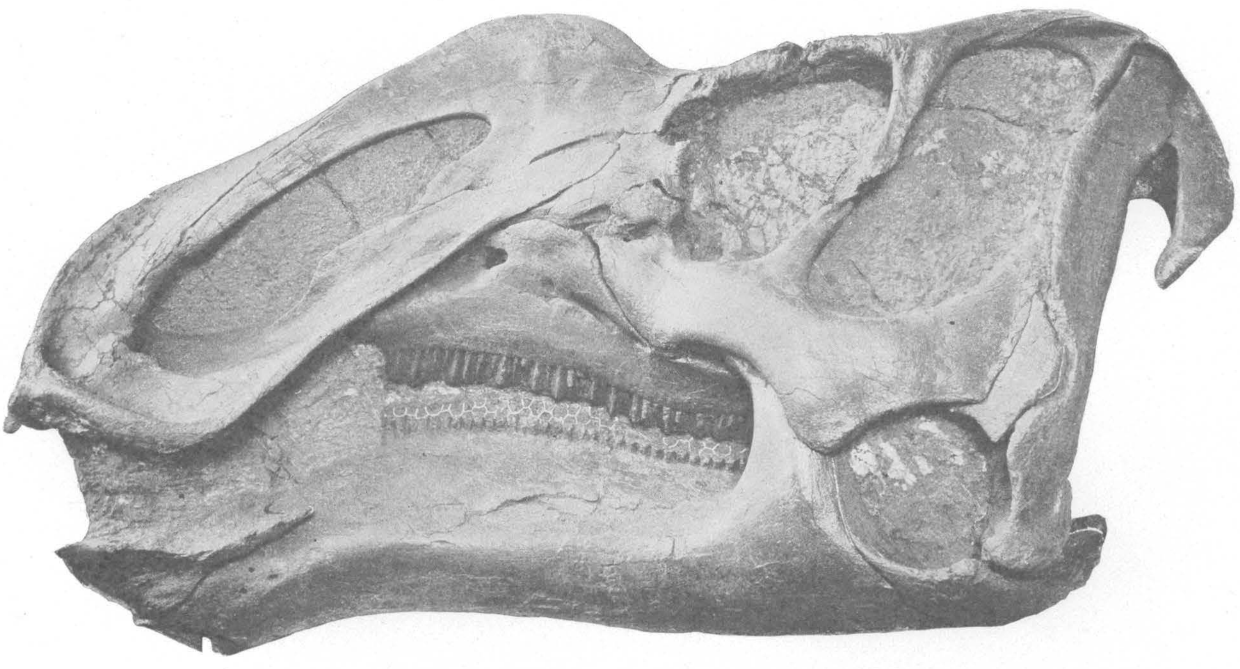
"One mile north of west of Ojo Alamo store; 25 feet below the upper conglomerate of Sinclair and Granger [locality 62, section F]. There is no lower conglomerate at this point; it is apparently consolidated with the upper." Upper part of Kirtland shale.

"North side of Barrel Spring Arroyo, half a mile west of wagon road from Ojo Alamo; 10 feet above lower conglomerate" (locality 63, section F). Ojo Alamo sandstone.

PLATES LXXII–LXXVIII.

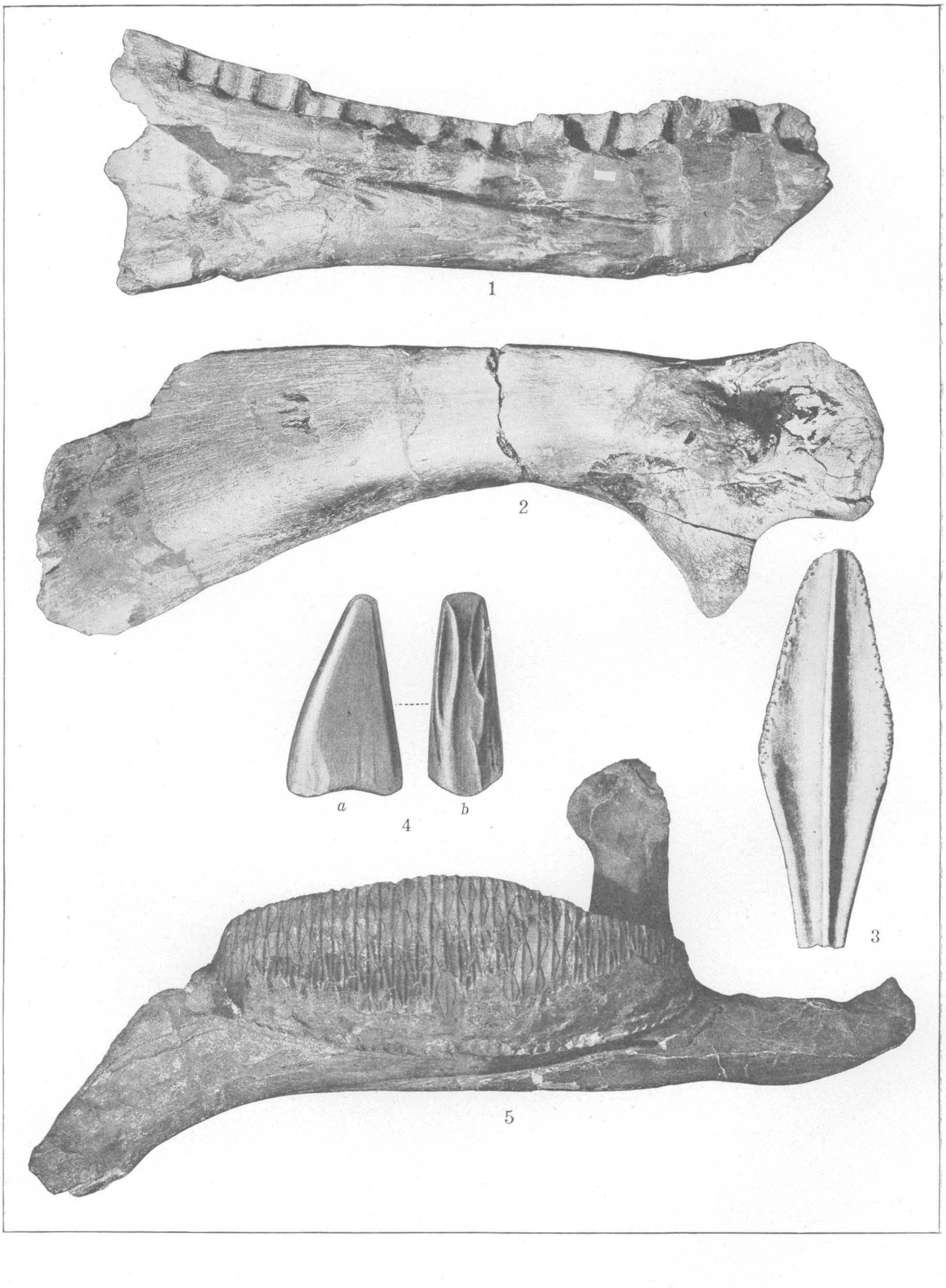
A. SKULL OF KRITOSAURUS NAVAJOVIUS BROWN.

Type. No. 5799, Am. Mus. Nat. Hist. About one-sixth natural size. A comparison with *B* shows that the nasal bones have not been properly restored. (After Brown.)



B. SKULL OF KRITOSAURUS NOTABILIS (LAMBE).

In the museum of the Geological Survey of Canada, Ottawa. Originally described as the type of Gryposaurus notabilis. About one-sixth natural size. (After Lambe.)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a
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b
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PLATE LXXIII.

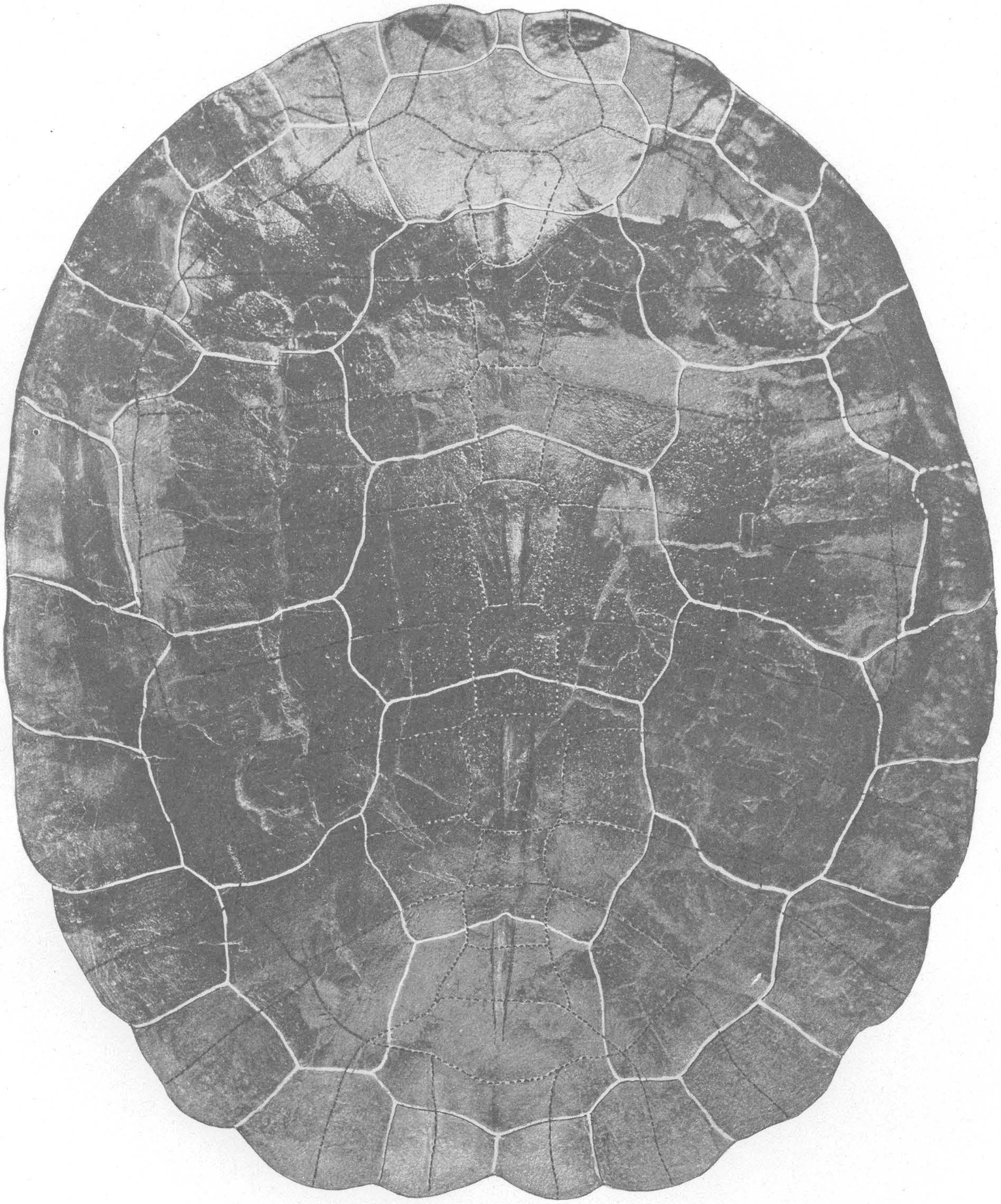
FIGURE 1. Left dentary of carnivorous dinosaur, possibly pertaining to the genus Deinodon. No. 8346, U. S. N. M. About one-third natural size.

FIGURE 2. Right scapula of Kritosaurus? sp. No. 8354, U. S. N. M. About one-fourth natural size.

FIGURE 3. Lower tooth of *Kritosaurus navajovius* Brown. Type. No. 5799, Am. Mus. Nat. Hist. Internal view. Enlarged 1½ diameters. (After Brown.)

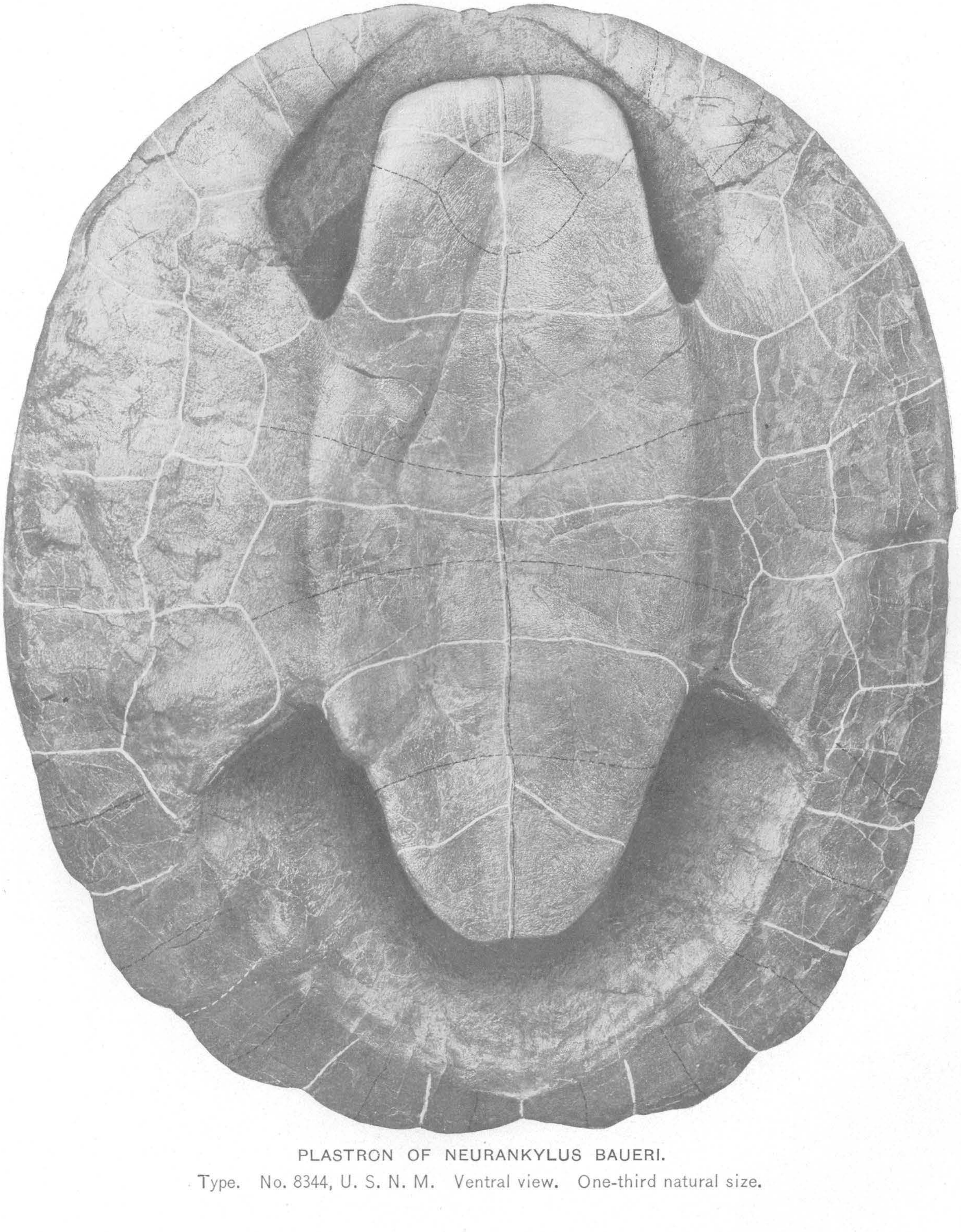
FIGURE 4. Tooth of carnivorous dinosaur. No. 8355, U. S. N. M. *a*, Lateral view; *b*, end view. Enlarged 2 diameters. This tooth resembles closely one figured and described by Leidy as pertaining to *Deinodon horridus*.

FIGURE 5. Right dentary of *Kritosaurus navajovius* Brown. Viewed from the internal side. Type. No. 5799, Am. Mus. Nat. Hist. About one-fifth natural size. (After Brown.)



CARAPACE OF NEURANKYLUS BAUERI.

Type. No. 8344, U. S. N. M. Dorsal view. One-third natural size.

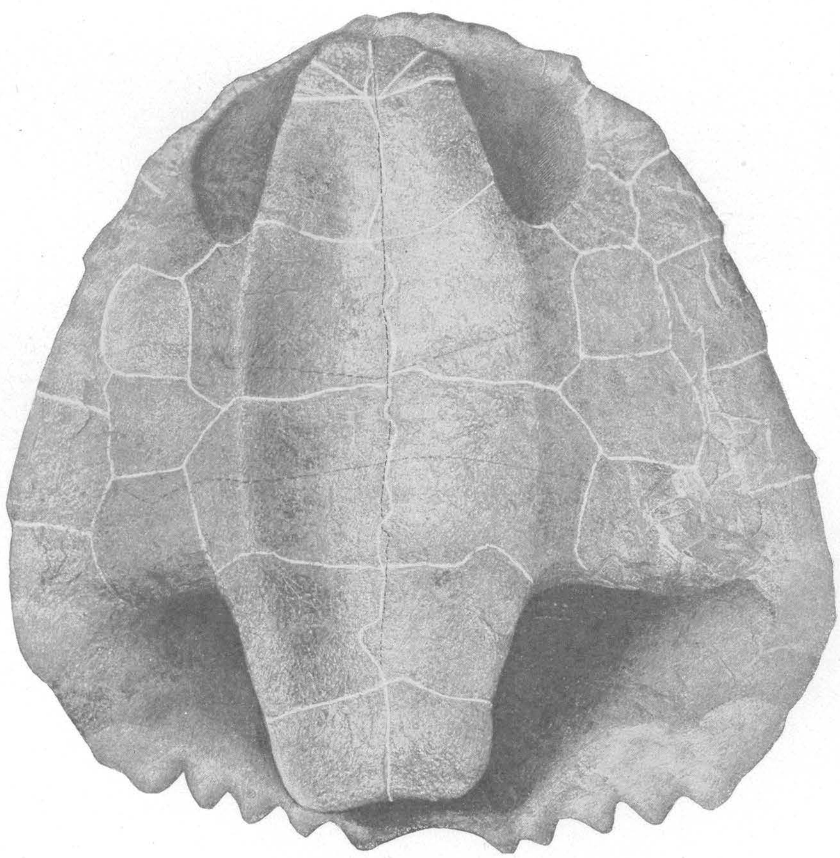


PLASTRON OF NEURANKYLUS BAUERI.

Type. No. 8344, U. S. N. M. Ventral view. One-third natural size.

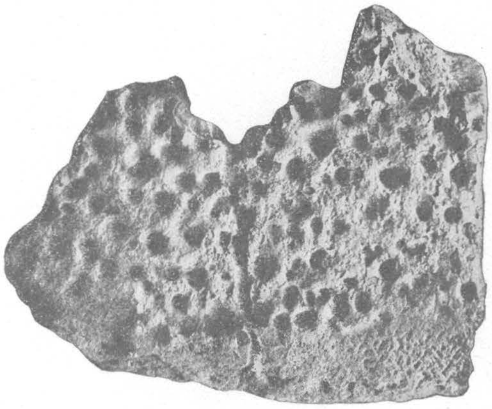
A. CARAPACE OF BAENA NODOSA.

Type. No. 8345, U. S. N. M. Dorsal view. One-fourth natural size.



B. PLASTRON OF THE SAME SPECIMEN.

Ventral view. One-fourth natural size.



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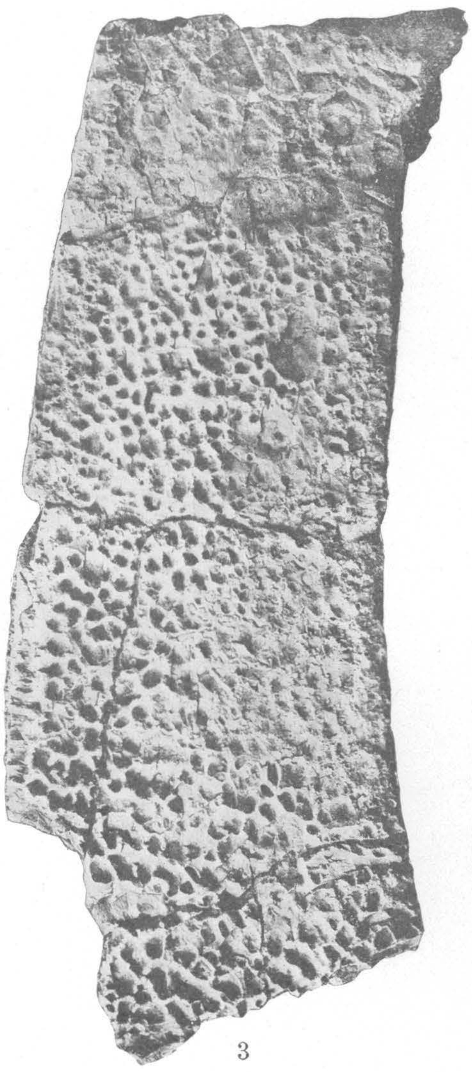

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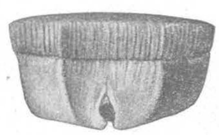

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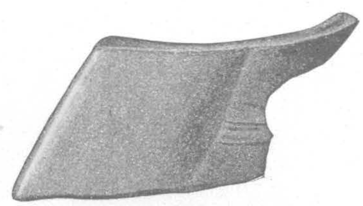

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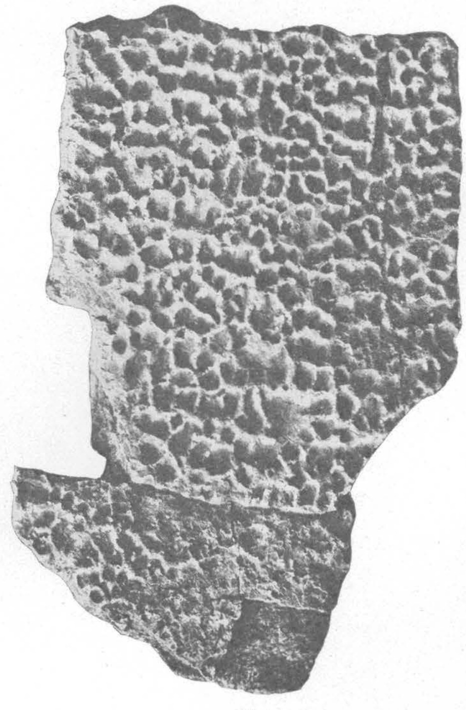


3a

PLATE LXXVII.

FIGURE 1. *Aspideretes austerus* Hay. Distal end of costal plate. No. 8351, U. S. N. M. Natural size. Shows the abruptly sunken pits which form the characteristic ornamentation of the carapace.

FIGURE 2. *Adocus vigoratus* Hay. Type. No. 6554, U. S. N. M. A part of a peripheral above the bridge to show the ornamentation. The upper border of the bone is toward the left. Natural size. (After Hay.)

FIGURES 3, 3^{a}. *Aspideretes vorax* Hay. Costal plates to show the ornamentation. No. 6550, U. S. N. M. Natural size.

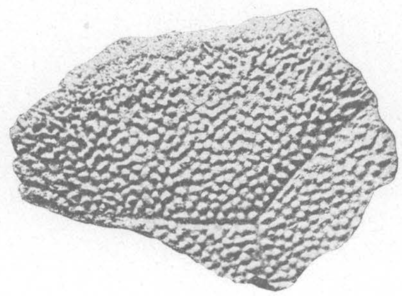
FIGURE 4. Myledaphus sp. Tooth. No. 8356, U. S. N. M. Enlarged 2 diameters.

FIGURE 5. Lepisosteus sp. Scale from the side of the body. No. 8357, U. S. N. M. Enlarged 2 diameters.

PLATE LXXVIII.

FIGURE 1. Plastomenus sp. Left hypoplastral bone. No. 8350, U. S. N. M. About three-fourths natural size.
FIGURE 2. Compsemys sp. Portion of a costal scute. No. 8349, U. S. N. M. Enlarged 2 diameters.
FIGURE 3. *Adocus vigoratus* Hay. Seventh peripheral, left side. No. 6554, U. S. N. M. Natural size.
FIGURE 4. *Adocus? lineolatus* Cope. Seventh peripheral, left side. No. 8348, U. S. N. M. Natural size.

1



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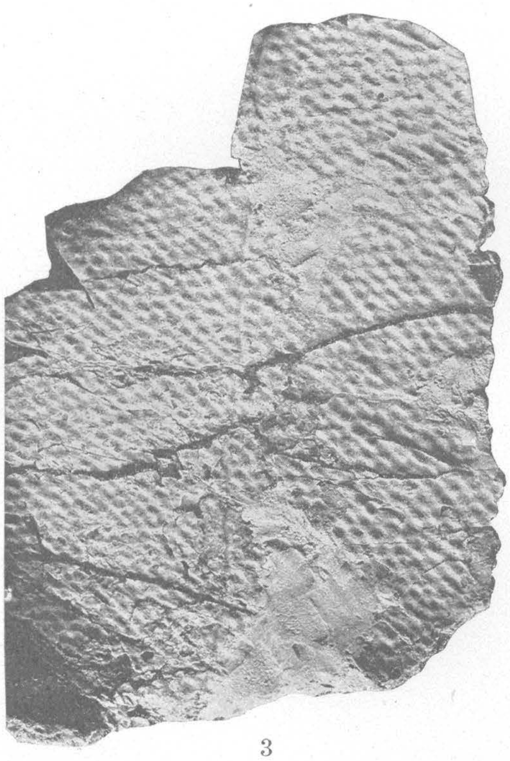

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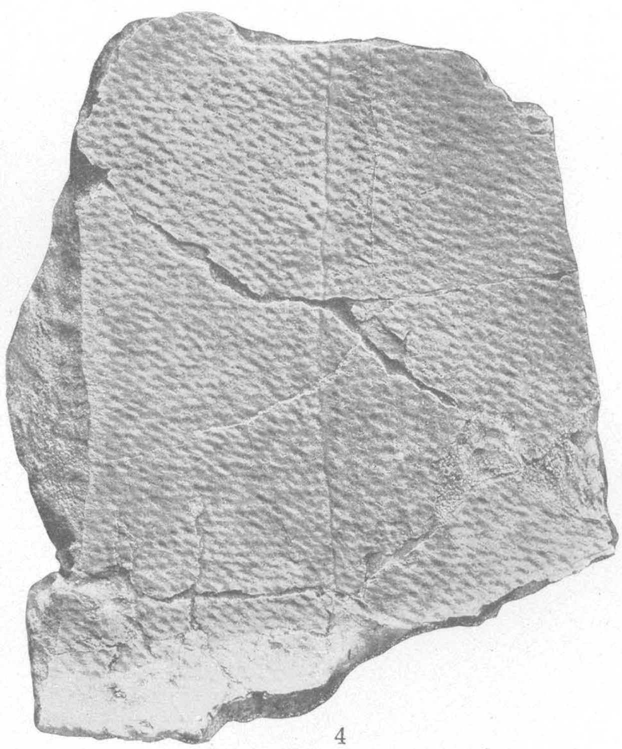


4

3. NONMARINE CRETACEOUS INVERTEBRATES OF THE SAN JUAN BASIN.

By T. W. Stanton.

In the San Juan Basin of New Mexico and southwestern Colorado the formations that have yielded marine Cretaceous faunas are, beginning at the base, the Mancos shale, the Mesaverde formation, the Lewis shale, and the Pictured Cliffs sandstone. The fossils obtained below the middle of the Mancos shale belong to the fauna of the Colorado group; those obtained above that line belong to the fauna of the Montana group.

East of the mountains, in the Denver Basin and more northern areas, the Montana group consists of the thick Pierre shale at the base and the thinner Fox Hills sandstone above. The faunas of these two formations are closely related, but each has its own distinctive species.

It might naturally be inferred from purely stratigraphic and lithologic considerations that the Pictured Cliffs sandstone should be correlated with the Fox Hills sandstone, for each is the latest marine sandstone in its respective section. The direct faunal evidence, however, does not support this correlation. Although the known fauna of the Pictured Cliffs sandstone consists of only a few species and, taken as an assemblage, agrees with the known stratigraphy in indicating late Montana age, it lacks all the strictly characteristic Fox Hills forms and includes some which are not known elsewhere above the Pierre shale. The fauna itself, therefore, suggests for the Pictured Cliffs sandstone an age slightly older than the Fox Hills.

Overlying the Pictured Cliffs sandstone with apparent conformity in the San Juan Basin and underlying the Puerco formation is a group of nonmarine sediments, coal bearing in the lower part, which in many previous reports have been referred more or less doubtfully to the Laramie formation. The rocks occupying this interval are fully described and a considerable area of them is mapped in the accompanying stratigraphic paper by C. M. Bauer,[1] who recognizes in them three formations—the Fruitland formation containing all the coal beds at the base, the Kirtland shale in the middle, and the Ojo Alamo sandstone at the top. The vertebrate fauna and the flora of these formations are described and discussed by C. W. Gilmore[2] and F. H. Knowlton,[3] respectively. The invertebrates, which form the subject of the present paper, nearly all come from the Fruitland formation. Of the 27 species discussed only two, *Unio pyramidatoides* and *U. baueri*, were collected in the Kirtland shale, and none was found in the Ojo Alamo sandstone. A few collections from southern Colorado a short distance north of the area mapped by Mr. Bauer have been included in the discussion because they are obviously from the equivalent of the Fruitland formation.

The general facts concerning the stratigraphic range and relationships of the invertebrate species may be most easily presented in tabular form, as shown on page 310.

The list of species shows that the nonmarine invertebrates of the Fruitland formation include both a fresh-water fauna and a brackish-water fauna. The latter is mostly confined to several thin bands in the lower half of the formation, though many of the collections show both fresh-water and brackish-water forms commingled. The Corbula and the Neritina especially are found with so many fresh-water associates at several localities that the suggestion is justified that they may have ranged into fresh waters, like some of their living congeners. The fresh-water fauna is especially notable for the greatly varied development of the genus Unio and for the abundance and considerable variety of the gastropods.

[1] U. S. Geol. Survey Prof. Paper 98-P.
[2] U. S. Geol. Survey Prof. Paper 98-Q.
[3] U. S. Geol. Survey Prof. Paper 98-S.

Stratigraphic range of nonmarine invertebrates of the San Juan Basin.

	Fruitland.	Kirtland.	Mesaverde.	Judith River.	Fox Hills.	Laramie of northeastern Colorado.	Lance.	"Lower Laramie" of southern Wyoming.	"Laramie" of southern Utah.
Ostrea glabra Meek and Hayden	x		x	x	x	x			
Anomia gryphorhynchus Meek	x		x	x		x			
Anomia gryphæiformis n. sp	x								
Modiola laticostata (White)	x		x						
Unio holmesianus White	x						x	x	r
Unio amarillensis n. sp	x						r	r	r
Unio pyramidatoides Whitfield?		x					x		
Unio gardneri n. sp	x						r		
Unio reesidei n. sp	x								r
Unio brachyopisthus White	x						x	x	
Unio baueri n. sp		x							
Unio neomexicanus n. sp	x						r		
Unio brimhallensis n. sp	x						x?		
Unio sp. cf. U. primævus White	x			r					
Corbicula cytheriformis (Meek and Hayden)	x		x	x		r	x		
Corbula chacoensis n. sp	x		r	r		r	r		
Panopæa simulatrix Whiteaves?	x								
Teredina neomexicana n. sp	x						r	r	
Neritina baueri n. sp	x								
Neritina (Velatella) sp	x						r	r	
Campeloma amarillensis n. sp	x			r			r		
Tulotoma thompsoni White	x		x			x	x	x	
Melania insculpta Meek?	x		x		x	x	x		
Goniobasis? subtortuosa Meek and Hayden	x			x					
Physa reesidei n. sp	x					r			
Physa sp	x								
Planorbis (Bathyomphalus) chacoensis n. sp	x								r

NOTE.—In this table "x" indicates the identical species named in the same horizontal line and "r" indicates a closely related form.

The distribution of the species as exhibited in the table may seem at first glance to indicate that the Fruitland fauna is about as closely related to the Mesaverde and Judith River faunas (which are approximately contemporaneous with each other) as it is to the Lance and Laramie faunas. A closer analysis of the table, however, will show that most of the species occurring or represented by related forms in the Mesaverde and Judith River are long-lived brackish-water species which range at least as high as the Laramie. *Melania insculpta* belongs to this class, for like all the other American Cretaceous species referred to Melania it is invariably associated with brackish-water forms. The only two Fruitland species with an outside distribution which do not elsewhere range into the higher formations are *Modiola laticostata*, from the Mesaverde, and *Goniobasis? subtortuosa*, from the Judith River. With the fresh-water species, especially those belonging to the genus Unio, the case is different. The majority of the identical and closely related species are found in the Laramie, the so-called "Lower Laramie" of southern Wyoming, and the Lance and do not range below these formations. It is my opinion, therefore, that the invertebrate evidence as a whole favors the assignment of the Fruitland formation to an epoch considerably later than Mesaverde and Judith River and possibly somewhat earlier than Lance. If due weight is given to the known stratigraphic relations and to the faunal evidence from the underlying formations, the Fruitland can hardly be older than Fox Hills, and the sequence from the base of the Fruitland up to the top of the Ojo Alamo, which is conformable, according to Mr. Bauer, may include the equivalents of everything from the Fox Hills to the Lance inclusive.

Ostrea glabra Meek and Hayden var.

Plate LXXIX, figures 1-3.

The New Mexican specimens referred to the widespread and long-lived species *Ostrea glabra* show scarcely perceptible differences from the variety from the Mesaverde formation at Point of Rocks, Wyo., described under the name *O. wyomingensis*. The species was originally described from the Judith River formation, but it also ranges into the Fox Hills, Laramie, and Lance formations.

Locality and position: The specimens here figured are from Bauer's locality 12, in Amarillo Canyon, 10 miles south of Jewett (locality 9279), in the Fruitland formation, 37 feet above its base. It was also collected from the same horizon 12 miles south of San Juan River and 2 miles east of Chaco River. Another lot provisionally identified as *O. subtrigonalis* Evans and Shumard, from Coal Creek, 37 miles south of Farmington, N. Mex., may be only young specimens of this species.

Anomia gryphorhynchus Meek.

Plate LXXIX, figures 7 and 8.

Anomia? gryphorhynchus Meek, U. S. Geol. Survey Terr. Fifth Ann. Rept., p. 375, 1872.

Anomia gryphorhynchus White, U. S. Geol. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 57, pl. 25, figs. 1a-c, 1880; U. S. Geol. Survey Third Ann. Rept., p. 16, pl. 12, figs. 12-15, 1883.

The New Mexican specimens of *Anomia gryphorhynchus* agree very well with the type lot from the Mesaverde formation at Point of Rocks, Wyo., especially with those individuals which have very fine radiating striæ, barely visible without a lens, though many of the Wyoming shells have no sculpture other than concentric growth lines. The species also occurs in the Laramie of Crow Creek, Colo., and in the Black Buttes coal group at Black Buttes station, Wyo.

An average specimen measures 20 millimeters in height and 18 millimeters in length.

Locality and position: In the lower part of the Fruitland formation 3 miles northwest of Fruitland, N. Mex. (locality 3475), where it is associated with *Modiola laticostata*, Corbicula, and other forms.

Anomia gryphæiformis Stanton, n. sp.

Plate LXXIX, figures 4-6.

Shell small, of variable outline, but usually much higher than long, very convex and with strongly incurved beaks, so that the general aspect is that of a small Gryphæa. Surface marked by conspicuous, threadlike radiating ribs, usually about 30 in number, varying considerably in size but relatively somewhat coarse compared with the size of the shell. Lower valve not seen.

The form varies considerably, as in all species of this genus, but most of the specimens seen resemble the one represented by figures 4 and 5, which measures 20 millimeters in height, 14 millimeters in length, and 12 millimeters in convexity of single valve. Another specimen representing nearly the extreme in variation is subcircular in outline, measuring 18 millimeters in height and length and 9 millimeters in convexity of single valve.

The coarser sculpture, smaller size, more slender convex form, and more conspicuous beaks distinguish this species from *A. micronema* Meek, which is probably its nearest relative in the western Cretaceous.

Locality and position: The types were collected by J. H. Gardner in the SE. ¼ sec. 19, T. 34 N., R. 4 W., in Colorado, from beds that are doubtless equivalent to the Fruitland formation. Other specimens came from Beaver Creek in T. 35 N., R. 6 W., in a neighboring part of southwestern Colorado.

Modiola laticostata (White).

Plate LXXIX, figures 9 and 10.

Volsella (Brachydontes) laticostata White, U. S. Geol. and Geog. Survey Terr. Bull., vol. 4, p. 708, 1878; U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 59, pl. 25, fig. 4a, 1880; U. S. Geol. Survey Third Ann. Rept., p. 423, pl. 13, fig. 2, 1883.

The type of this species is from the Danforth Hills, near White River Indian Agency, Colo., where it occurs in beds now referred to the Mesaverde. It is incomplete at both ends, but in form and sculpture it agrees perfectly with some of the larger and much better preserved specimens from New Mexico here referred to the species. The two examples figured show that the species varies in breadth and curvature, but the variation in these particulars is even greater than they indicate.

Locality and position: All the New Mexican examples are from the lower part of the Fruitland formation near Fruitland. The two figured were collected by the late Robert Forrester and labeled "Fruitland" (locality 7077). Other lots were collected by Schrader and Shaler 3 miles northwest of Fruitland, a quarter of a mile southeast of the Bruce mine (locality 3475), and by Gardner at Thurling's limekiln, 4 miles north of Fruitland (locality 4002).

Unio holmesianus White.

Plate LXXX, figures 1–7.

Unio holmesianus White, U. S. Geol. and Geog. Survey Terr. Bull., vol. 3, p, 604, 1877; U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 67, pl. 22, figs. 4a–e, 1880; U. S. Geol. Survey Third Ann. Rept., p. 433, pl. 17, figs. 2–6, 1883.

The published descriptions and figures of this striking species are full and accurate except in some minor details of sculpture, which are not well preserved on the types and were slightly misinterpreted by the artist, as may be seen by comparing the original figures with the photographs of the same specimens as reproduced in figures 1 and 2. The radiating ridges on the posterior part of the larger specimen are in part due to accidental distortion and are not conspicuous on any other adult shell in the type lot.

The strong beak sculpture, which is the characteristic feature of the species, covers the umbonal region of the shell for a distance of 16 to 20 millimeters from the apex. It consists near the apex of sharp, slightly undulating concentric ridges which are almost parallel with the growth lines, but within a short distance these ridges become more wavy and develop a deep V-shaped sinus with its apex in the broad umbonal furrow that lies just in advance of the posterior umbonal ridge. Subordinate sinuses are developed on the anterior portion of some shells. The anterior part of the shell thus becomes covered with strong undulating ridges which run from the anterior margin obliquely backward and downward to the umbonal furrow. The rather narrowly rounded umbonal ridge is usually crossed by several short transverse ridges that are almost at right angles to the main sculpture of the front part of the shell, where the continuation of this second system of ridges is sometimes faintly shown. Small irregular radiating lines with varying development on different individuals diverge from the umbonal ridge, some passing to the posterior margin and others toward or to the basal margin, thus extending farther on the adult shell than the other elements of beak sculpture. Well-preserved shells also show a threadlike raised line running from the beak down the crest of the umbonal ridge and a similar line midway between it and the posterior margin.

The dimensions given by White (length 45 millimeters, height 42 millimeters) are about the average for an adult shell.

Geographic and stratigraphic distribution: The specimen from which this species was originally described was found near the base of the coal-bearing rocks near Black Buttes station, Wyo. The beds at this locality have at different times and by different geologists been assigned to the Wasatch, the Laramie, the Lance, and a horizon intermediate between the Laramie and Lance. My own opinion is that the beds should be correlated with the lower part of the Lance. *Unio holmesianus* has also been collected from the Lance formation on Lance Creek, Wyo., and Fish Creek, Mont., from beds of approximately the same age near Belfry, Mont., and from the "Lower Laramie" as mapped by Veatch 3 miles west of Carbon, Wyo. A closely similar if not identical form described by Whitfield under the name *U. browni* was obtained from the "Hell Creek beds," now referred to the Lance formation on Snow Creek, 130 miles northwest of Miles City, Mont.

In the San Juan Basin of New Mexico and Colorado the species has been found only in the Fruitland formation, which in the past has sometimes been tentatively referred to the Laramie. It was collected by C. M. Bauer's party from his localities 4, 14, 17, 18, and 77, which are, respectively, 40 feet above the base of the formation, 1 mile south of Fruitland (locality 9268); 115 to 140 feet above the base (locality 9270), 140 feet above the base (locality 9271), and 150 feet above the base (locality 9272) in Amarillo Canyon, 10 miles south of Jewett; and 200 feet above the base near Hunter's store, 30 miles south of San Juan River (locality 9293). One broken specimen from locality 9271 showing beak sculpture is represented by figure 5. The material from the above-named localities is ample for identification, but the specimens are less perfect than those selected for figuring from the collection of J. H. Gardner from the Ignacio quadrangle, Colo. The specimens represented by figures 3 and 4 were collected 8 feet above "B" coal in sec. 16, T. 35 N., R. 7 W. (locality 6071), and those shown by figures 6 and 7, 300 feet below the top of the "Laramie" in sec. 19, T. 35 N., R. 8 W. (locality 6063). For comparison with these figures new illustrations of White's types are given in figures 1 and 2. The smaller shell is the original type, on which the first description was based.

Unio amarillensis Stanton, n. sp.

Plate LXXX, figures 8 and 9.

Shell small, moderately convex, subquadrangular to subcircular in outline, with height and length nearly equal; beaks rather prominent, near middle of hinge line; dorsal margin descending rapidly and slightly excavated in front of the beak, very gently convex behind it; anterior and ventral margins regularly rounded; posterior margin subtruncate; surface strongly sculptured for a distance of about 10 millimeters from the apex of the beak, the sculpture consisting at the apex of concentric ridges each with a deep V-shaped sinus on the umbonal ridge and a shallower one near the middle, but within a short distance these sinuses fade out into the smooth surface of the shell and only the obliquely descending anterior and posterior portions of the ridges are developed. Beyond the distance of 10 millimeters from the beak the shell bears only fine lines of growth except on the short posterior slope, where there are five to seven rather strong plications that descend obliquely from the faintly marked umbonal ridge to the posterior margin. Height of type, which may be immature, 27 millimeters; length 29 millimeters.

This specimen belongs in the group of *U. holmesianus*, though in sculpture it shows relationship with *U. verrucosiformis* Whitfield and *U. letsoni* Whitfield, both of which differ from it in form and in having a line of nodes down the middle of the valve.

Locality and position: The type lot consists of three valves from Bauer's locality 14, in Amarillo Canyon, 10 miles south of Jewett, N. Mex. (locality 9270), 115 to 140 feet above the base of the Fruitland formation. Five specimens from the Lance formation on the divide between Lance and Lightning creeks, Wyo. (U. S. N. M., catalogue No. 23364), are believed to belong to this species, though they are slightly larger and their beak sculpture is not perfectly preserved.

Unio pyramidatoides Whitfield?

Plate LXXX, figures 12 and 13.

Unio pyramidatoides Whitfield, Am. Mus. Nat. Hist. Bull., vol. 23, p. 624, pl. 41, figs. 1-5, 1907.

The imperfect specimens doubtfully referred to *Unio pyramidatoides* have very nearly the same form as *U. holmesianus* White, but they are very much larger and thicker than that species, and the beak sculpture, so far as it is still discernible on the eroded beaks, while of the same general type is not so strong and does not extend over so much of the shell. In all these features of size and sculpture they are more like *U. pyramidatoides*, though fuller collections of better-preserved material may prove that they belong to a distinct species.

The larger specimen figured measures 70 millimeters in height and about 72 millimeters in length. A slightly crushed specimen from Yellow Jacket Creek, Colo., measures 73 millimeters in height and 76 millimeters in length.

Locality and position: The figured specimens were obtained at Bauer's locality 32, 17 miles south of San Juan River and 6 miles east of Chaco River, N. Mex. (locality 9276), in the Kirtland shale 150 feet above its base. Another specimen believed to belong to the same species comes from either the Kirtland shale or the Fruitland formation on Yellow Jacket Creek in T. 34 N., R. 5 W., Colo.; and two small examples, which may be young shells of the species, were found 140 feet above the base of the Fruitland formation in Amarillo Canyon, 10 miles south of Jewett, N. Mex. (locality 9271). Whitfield's types came from beds now referred to the Lance formation on Snow Creek, 130 miles northwest of Miles City, Mont. The species has also been recognized in the Lance on Fish Creek, Mont.

Unio gardneri Stanton, n. sp.

Plate LXXX, figures 10 and 11.

Shell small, subcircular in outline, very convex; beaks prominent, strongly incurved, somewhat flattened, situated near the middle of the hinge line; anterior, ventral, and posterior margins forming a nearly regular curve; dorsal margin straighter. Surface strongly sculptured for a distance of about 20 millimeters from the apex of the beak, the sculpture consisting primarily of concentric ridges on which two deep V-shaped sinuses develop—one on the posterior umbonal ridge and the other near the median line of the shell. Within a short distance these ridges break up into oblique, more or less curved lines of nodes, and there are also developed two radiating lines of irregular tubercles, one down the middle of the shell and the other on the posterior umbonal ridge, and behind this ridge a number of small irregular curved ribs that extend from it toward but not to the posterior margin. The rest of the surface shows only lines of growth.

Height of type specimen 38 millimeters; length 43 millimeters; convexity of single valve 14 millimeters.

This species belongs to the group of *Unio letsoni* Whitfield, of the Lance formation, from which it differs in being more convex, in having two lines of tubercles instead of one, and in having much less conspicuous sculpture on the posterior portion of the shell.

The species is named for Mr. James H. Gardner, who collected the type.

Locality and position: Sec. 19, T. 35 N., R. 8 W., Ignacio quadrangle, Colo. (locality 6063), about 300 feet below the top of the "Laramie," probably in the upper part of the Fruitland formation.

Unio reesidei Stanton, n. sp.

Plate LXXXI, figure 1.

Shell rather small, broadly subelliptical in outline, strongly convex; beaks very inconspicuous, situated about one-third the length of the shell behind the front; anterior margin forming a regular curve from the beak to the ventral margin, which is more broadly curved; dorsal margin behind the beak gently convex, and posterior margin slightly subtruncate. Beak sculpture not preserved on the specimens studied. Surface in advance of the inconspicuous umbonal ridge marked only by fine lines of growth; posterior portion, comprising about two-fifths of the total surface, marked by 8 or 9 distinct but somewhat irregular radiating plications decreasing in size from the umbonal ridge backward and upward.

Height of figured type 46 millimeters; length (restored) 62 millimeters. A small specimen measures 39 millimeters in height, 49 millimeters in length, and 33 millimeters in greatest convexity of both valves united.

The species is named for Mr. J. B. Reeside, jr., of the United States Geological Survey.

In general features of form and sculpture this species suggests *U. gonionotus* White, from the "Laramie" of Sevier Cliffs, 10 miles above Panguitch, Utah, but it is easily distinguishable by its stouter form and the smaller size and different shape of the posterior plications.

Locality and position: The type specimen was obtained at Bauer's locality 48, 25 miles south of San Juan River and 6 miles east of Chaco River, N. Mex. (locality 9288), about 150 feet above the base of the Fruitland formation. Other specimens were collected at Bauer's locality 21, 12 miles south of the San Juan and 2 miles east of the Chaco (locality 9281) at about the same horizon.

Unio brachyopisthus White.

Plate LXXXI, figures 2 and 3.

Unio brachyopisthus White, in Powell, Geology of the eastern portion of the Uinta Mountains, p. 126, U. S. Geol. and Geog. Survey Terr., 2d div., 1876; U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 64, pl. 22, figs. 2 a, b, 1880; U. S. Geol. Survey Third Ann. Rept., p. 433, pl. 16, figs. 7, 8, 1883.

This species, originally described from specimens found in the coal-bearing rocks at Black Buttes station, Wyo., is widely distributed in the so-called "Lower Laramie" of southern Wyoming and in the Lance formation in the eastern part of the State. It varies considerably in outline, even at the original locality, and the small type specimen is relatively shorter and higher than the average. In the San Juan Basin it is represented by the typical form (fig. 3) at Yellow Jacket Creek, Colo. (locality 7079), and by a more elongate form (fig. 2) at Bauer's locality 18, in Amarillo Canyon, 10 miles south of Jewett, N. Mex. (locality 9272), 150 feet above the base of the Fruitland formation.

Unio baueri Stanton, n. sp.

Plate LXXXI, figure 6.

Shell of medium size, subovate in outline, convex and thick; beaks prominent, situated in the anterior third of the shell; dorsal margin in front of the beak descending steeply into the broadly rounded front margin; postero-dorsal margin nearly straight and forming an obtuse angle with the subtruncate posterior margin; ventral margin very broadly convex. Beak sculpture not preserved on the type. The rest of the shell marked by irregular broad, rounded radiating plications which are strongest just behind the umbonal ridge and are separated by much narrower shallow furrows.

Height of type 57 millimeters; length 89 millimeters; convexity of single valve about 35 millimeters.

The species is named for Mr. C. Max Bauer.

Locality and position: At Bauer's locality 32, about 17 miles south of San Juan River and 6 miles east of Chaco River, N. Mex. (locality 9276), 150 feet above the base of the Kirtland shale.

Unio neomexicanus Stanton, n. sp.

Plate LXXXI, figures 4 and 5.

Shell small to medium, obliquely ovate in outline, moderately convex; beaks moderately prominent, at anterior end of shell; front margin descending abruptly with very slight curvature from the beaks for three-fourths of the height and then curving backward more rapidly to join the nearly straight (slightly convex) ventral margin; posterior end obliquely subtruncate above and broadly rounded below. A rather prominent rounded umbonal ridge extends obliquely from the beak to the postero-ventral margin, and in front of this is a broad, shallow depressed area. Beak sculpture not well preserved but apparently confined to a small area and consisting of irregular concentric ridges. The crest of the umbonal ridge bears a threadlike elevated line, especially in the umbonal region, and a similar line is midway between this and the postero-dorsal margin. The rest of the shell shows only fine lines of growth.

Height 39 millimeters; length 60 millimeters; convexity of single valve 19 millimeters.

Unio neomexicanus is related to *U. proavitus* White, which is found in the coal-bearing rocks at Black Buttes, Wyo., and in the Lance formation on Lance Creek, eastern Wyoming. The Wyoming species differs in details of outline and has much more prominent beaks.

Locality and position: Represented by two left valves from the Fruitland formation, 150 feet above its base, at Bauer's locality 48, 25 miles south of the San Juan and 6 miles east of Chaco River, N. Mex. (locality 9288).

Unio brimhallensis Stanton, n. sp.

Plate LXXXI, figure 7; Plate LXXXII, figure 1.

Shell large, transversely broad ovate, gently convex; beaks prominent, situated about one-fourth the length of the shell from the front; dorsal margin deeply excavated in front of the beaks and almost straight behind them; anterior and posterior margins broadly and almost equally rounded; ventral margin more broadly rounded. Surface marked only by ordinary lines of growth on the anterior half of the valve. The rest of the surface not preserved except traces of faint radial sculpture near the dorsal margin behind the beaks.

The types are two imperfect valves, one of which shows the front part of the shell and the other preserves the outline of the posterior part. The better specimen measures 93 millimeters in height and has a convexity of about 30 millimeters and an estimated length of about 130 millimeters.

This species or a closely similar form is represented by a cast retaining part of the shell from the Lance formation between Lance and Lightning creeks, eastern Wyoming. The specimen measures 102 millimeters in height and 140 millimeters in length.

Locality and position: On Brimhalls Wash at Bauer's locality 48, about 25 miles south of San Juan River and 6 miles east of Chaco River, N. Mex. (locality 9288), 150 feet above the base of the Fruitland formation.

Unio sp.

Plate LXXXII, figures 2 and 3.

cf. *Unio primævus* White, U. S. Geol. and Geog. Survey Terr. Bull., vol. 3, p. 599, 1877; U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 70, pl. 29, figs. 3 a, b, 1880; U. S. Geol. Survey Third Ann. Rept., p. 432, pl. 14, figs. 4, 5, 1883.

Several small, poorly preserved specimens evidently represent a distinct species of Unio that may be compared with the Judith River form *U. primævus* White, from which it differs in its more anterior beaks, more angular and prominent posterior umbonal ridge, and probably in details of sculpture. These differences are probably of specific value, but on account of distortion and other accidents of preservation it is impossible to give a full, accurate specific description or even to decide whether all the specimens here grouped together belong to a single species. For similar reasons *U. primævus*, with which these specimens are compared, is in the same uncertain status.

Of the two specimens figured the smaller one, which is only an exfoliated fragment showing the umbonal region, is believed to represent nearly the normal form. The larger one is obliquely compressed so that the posterior area behind the umbonal ridge is much shortened.

Locality and position: The smaller specimen was obtained from the Fruitland formation about 150 feet above its base at Bauer's locality 48, 25 miles south of San Juan River and 6 miles east of Chaco River (locality 9288); the larger one 40 feet above the base of the same formation at Bauer's locality 4, 1 mile south of Fruitland, N. Mex. (locality 9268). Another specimen was found 140 feet above the base of the Fruitland formation at Bauer's locality 21, 12 miles south of San Juan River and 2 miles east of the Chaco.

Corbicula cytheriformis Meek and Hayden.

Plate LXXXII, figure 4.

Cyrena (*Corbicula?*) *cytheriformis* Meek and Hayden, Acad. Nat. Sci. Philadelphia Proc. for 1860, p. 176, 1860.

Corbicula cytheriformis Meek, U. S. Geol. Survey Terr. Rept., vol. 9, p. 520, pl. 40, figs. 5a–c, 1876; White, U. S. Geol. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 74, pl. 21, figs. 4a–d, 1880; U. S. Geol. Survey Third Ann. Rept., p. 437, pl. 22, figs. 1–6, 1883.

In the brackish-water fauna that is found in the lower part of the Fruitland formation the genus Corbicula is abundant at certain localities, especially in the neighborhood of Fruitland. Several species may be represented by more or less distorted and imperfect material. The form here figured, however, agrees in every particular with the types of *C. cytheriformis* from the Judith River formation of Montana. The species is widely distributed in the Mesaverde formation and also ranges up into the Lance formation.

Locality and position: The specimen figured came from Bauer's locality 36, 120 feet above the base of the Fruitland formation, 18 miles south of San Juan River and 3 miles east of Chaco River, N. Mex. (locality 9286), where it is associated with *Corbula chacoensis*, *Neritina baueri*, Viviparus, *Campeloma amarillensis*, and *Tulotoma thompsoni*.

Corbula chacoensis Stanton, n. sp.

Plate LXXXII, figures 5 and 6.

Shell of medium size, subtriangular in outline, moderately convex; beaks prominent, situated slightly in advance of the middle of the hinge line; dorsal margin descending steeply before and behind, the two portions making an angle of about 110°; anterior end and ventral margin broadly rounded; posterior end narrowed and obliquely subtruncate; surface marked only by numerous fine concentric growth lines until the shell has attained about three-fourths the dimensions of a full-grown individual, after which strong concentric corrugations are developed on the ventral part of the shell and the convexity becomes relatively greater.

Height 16 millimeters; length 22 millimeters; convexity of the two valves 12 millimeters.

The species is related to *Corbula subtrigonalis* Meek and Hayden, from which it differs in its more nearly equilateral form and other details of outline and in the much stronger corrugations at the later stages of growth.

Locality and position: The type came from the lower part of the Fruitland formation at Bauer's locality 25, about 13 miles south of San Juan River and 1 mile east of Chaco River, N. Mex. (locality 9284). The collection from this place contains 18 individuals in addition to the figured type. The species is abundantly represented, mostly by immature individuals, half a mile north of this locality, and it was collected at several other localities ranging from 18 to 28 miles south of San Juan River.

Panopæa simulatrix Whiteaves?

Panopæa simulatrix Whiteaves, Contr. Canadian Paleontology, vol. 1, p. 11, pl. 2, figs. 2, 2a, 1885.

Several casts obtained at Bauer's locality 51, in the Fruitland formation 120 feet above its base, 28 miles south of San Juan River, and 6 miles east of Chaco River, N. Mex. (locality 9290), represent either this species or one closely related to it. Whiteaves's species occurs in Canada and Montana in the Judith River formation, and a closely similar if not identical form is found near the top of the Fox Hills sandstone in South Dakota.

Teredina neomexicana Stanton, n. sp.

Plate LXXXII, figures 7-10.

cf. *Xylophomya laramiensis* Whitfield, Am. Mus. Nat. Hist. Bull., vol. 16, pp. 73-76, pls. 28, 29, 1902.

Shell small, subglobose, broadly gaping in front and behind and with the posterior ends of the valves prolonged into a tapering, somewhat tortuous shelly tube several times the length of the valves themselves; anterior gape, which is formed by a rectangular notch in each valve, closed by a shield-shaped plate or callus with median furrow or suture; posterior end of valve broadly subangular. Surface marked by distinct growth lines parallel to the margins, by a narrow umbonal furrow corresponding in position to an internal rib or thickening, extending from the beak to the ventral margin, and by a less conspicuous furrow extending from the beak to the lateral angle of the anterior gape. One of the types shows fragments of an umbonal accessory valve.

Height of best-preserved type, 12 millimeters; length of valve, 12 millimeters; convexity of united valves, 12 millimeters.

A tube associated with the types and believed to belong to the same species indicates dimensions nearly twice as great.

This burrowing shell seems to be referable to the genus Teredina Lamarck, though it is also certainly congeneric with the Lance species for which Whitfield proposed the new name Xylophomya. Through the courtesy of the American Museum of Natural History it has been possible to make direct comparisons with the type specimens of *Xylophomya laramiensis*, on which the genus was based. The study of these specimens, which came from the Lance formation near Alkali Creek,[1] eastern Wyoming, and of large collections, apparently belonging to the same species, from the "Lower Laramie" opposite the mouth of Medicine Bow River, Carbon County, Wyo., shows that they have all the generic characters of Teredina and that they differ from the New Mexico shell here described only in their larger size and in slight differences in the outline of the posterior end of the valve. Whitfield described the hinge of Xylophomya as having "four minute toothlike denticles on the right valve anterior to the beaks," and the figure as well as the fragment itself suggests taxodont teeth at first glance, but a closer examination shows that they can not be hinge teeth, for they are strictly marginal and connected with the outer surface, and the shell was doubtless edentulous like other members of its family.

Locality and position: At Bauer's locality 22, near the base of the Fruitland formation, 12½ miles south of San Juan River and 1 mile east of Chaco River, N. Mex. (locality 9283), associated with *Corbula chacoensis*, with several species of Unio, and with *Tulotoma thompsoni* and other fresh-water gastropods.

Neritina baueri Stanton, n. sp.

Plate LXXXIII, figures 1-4.

Shell large, subglobose, consisting of about three very rapidly increasing volutions; spire so much depressed that it scarcely projects above the general curved surface of the shell; aperture nearly semicircular, with sharp outer lip and broadly flattened, simple inner lip; surface polished and without sculpture except numerous very fine growth lines but on well-preserved specimens retaining the color pattern, which consists of numerous irregular dark-brown spots and bands, some of which tend to have a spiral arrangement, while others run in zigzag fashion nearly parallel with the growth lines. The color pattern varies in different individuals.

The largest specimen collected, which is figured as the type, measures 38 millimeters in height and 37 millimeters in greatest breadth. The smaller figured specimen is believed to be a young individual of the same species.

This species is much larger than any other American Cretaceous Neritina that has been described, and it is also distinct in form and proportions.

Localities and position: The type was obtained at Bauer's locality 21, about 140 feet above the base of the Fruitland formation, 12 miles south of San Juan River and 2 miles east

[1] Mr. Barnum Brown, who collected these fossils, states in a personal letter that the locality is on the "east side of Alkali Creek, 3 miles from the mouth and not more than 50 feet above the Fox Hills or marine Cretaceous."

of Chaco River (locality 9281), where six other specimens were collected. The other figured specimen came from about the same horizon in Amarillo Canyon, 10 miles south of Jewett, N. Mex. (locality 9270), and others were collected in the same neighborhood (locality 9271). One lot of nine small specimens referred to this species was found near the base of the Fruitland formation, 12½ miles south of San Juan River, and 1 mile east of the Chaco (locality 9283), and one imperfect cast 200 feet above the base of the Fruitland formation, 17 miles south of the San Juan (locality 9285).

Neritina (Velatella) sp.

A single small, imperfect specimen belonging to Meek's subgenus Velatella was collected in the Fruitland formation, 120 feet above the base, at Bauer's locality 36, 18 miles south of San Juan River and 3 miles east of Chaco River, N. Mex. (locality 9286). In size and form it does not differ greatly from *Neritina* (*Velatella*) *baptista* White, which was originally described from specimens obtained in the lower part of the coal-bearing formation at Black Buttes station, Wyo., and which has also been found in the Laramie of northeastern Colorado.

Campeloma amarillensis Stanton, n. sp.

Plate LXXXIII, figures 5 and 6.

Shell small, rather slender, consisting of about 6 moderately convex whorls that are slightly compressed above; suture distinctly impressed; surface nearly smooth but showing when magnified fine, slightly sinuous growth lines and, especially on the upper part of the last whorl, fine raised revolving lines; aperture ovate, with length a little less than half the height of shell.

Height of larger figured type, 22 millimeters; greatest breadth, 13 millimeters; height of aperture, 10 millimeters; breadth of aperture, 7 millimeters. Apical angle about 40°.

In size, general form, and other external features this species is intermediate between *Campeloma vetula* Meek and Hayden, from the Judith River formation, and *C. producta* White, from the Fort Union.

Locality and position: The types came from Bauer's locality 14, in Amarillo Canyon, 10 miles south of Jewett, N. Mex. (locality 9270), in the Fruitland formation, 115 to 140 feet above its base. The species was collected at several other localities, ranging from 12 to 25 miles south of San Juan River and from 50 to 300 feet above the base of the Fruitland formation.

Tulotoma thompsoni White.

Plate LXXXIII, figures 9-11.

Tulotoma thompsoni White, in Powell, Geology of the eastern portion of the Uinta Mountains, p. 134, U. S. Geol. and Geog. Survey Terr., 2d div., 1876; U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 100, pl. 28, figs. 2a-h, 1880; U. S. Geol. Survey Third Ann. Rept., p. 467, pl. 24, figs. 17-22, 1883.

This well-characterized and easily recognized species was first found at Black Buttes station, Wyo., in the lower part of the Black Buttes coal group, which, in my opinion, should be correlated with the "Lower Laramie" of Carbon County, Wyo., and with the Lance formation. The species has a wide distribution in the Lance formation in Wyoming and Montana and is abundant in the Laramie on Crow Creek, Colo., where a number of the specimens figured by White were obtained. It has also been found abundantly and typically developed in the Mesaverde formation of northwestern Colorado, especially in the upper part of the formation near Axial, Colo.

Locality and position: The specimens figured came from Bauer's locality 14, in Amarillo Canyon, 10 miles north of Jewett, N. Mex. (locality 9270), in the Fruitland formation 115 to 140 feet above its base. The species ranges through the entire thickness of the Fruitland and has been collected at many localities.

Melania insculpta Meek?

Melania insculpta Meek, U. S. Geol. Survey Terr. Sixth Ann. Rept., for 1872, p. 515, 1873.

White, U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 94, pl. 20, fig. 4a, 1880; U. S. Geol. Survey Third Ann. Rept., p. 54, pl. 26, figs. 4, 5, 1883.

Two collections obtained near the base of the Fruitland formation at Bauer's localities 22 and 25, 12½ and 13 miles south of San Juan River, N. Mex. (localities 9283 and 9284), and one collection obtained near the middle of the same formation at Bauer's locality 51, 15 miles farther south (locality 9290), contain imperfect specimens of a Melania which in form and sculpture seems to agree very well with *M. insculpta* Meek. The specimen from which this species was first described was found in rocks now referred to the Mesaverde formation near Rock Springs, Wyo., and it also occurs in the Laramie of northeastern Colorado.

Goniobasis? subtortuosa (Meek and Hayden) Meek.

Plate LXXXIII, figures 7 and 8.

Melania subtortuosa Meek and Hayden, Acad. Nat. Sci. Philadelphia Proc., vol. 9, p. 136, 1857.
Goniobasis? subtortuosa Meek, U. S. Geol. Survey Terr. Rept., vol. 9, p. 569, pl. 42, figs. 17a, b, text figs. 75, 76, 1876.
White, U. S. Geol. Survey Third Ann. Rept., p. 57, pl. 27, fig. 34, 1883.
Whiteaves, Contr. Canadian Paleontology, vol. 1, p. 74, pl. 10, fig. 7, 1885.

Meek's description based on specimens from the Judith River formation near the mouth of Judith River, Mont., is as follows:

Shell conoid-screw-shaped, thin; spire rather low; volutions about five, very convex, and strongly carinate around the middle, increasing rather rapidly in size from the apex; suture deep in consequence of the prominence of the angular whorls; surface with moderately distinct lines of growth; aperture rhombic-suboval, about as long as wide. Length 0.39 inch; breadth 0.21 inch; slopes of spire nearly straight, with a divergence of 47°. Some crushed specimens show that it attained nearly twice the linear dimensions of that from which the above measurements were taken.

Better material than Meek had, from both Montana and Alberta, shows that adult shells consist of six or seven whorls and that they vary considerably in proportions. A few specimens which retain part of the surface of the shell when magnified show very faint revolving lines on the last whorl, especially above the carina, and agree in this feature, as well as in form, with the well-preserved specimens from New Mexico that are referred to the species.

The larger specimen figured measures 20 millimeters in height and 12 millimeters in breadth.

Locality and position: At Bauer's localities 14, 15, and 17, in Amarillo Canyon, 10 miles south of Jewett, N. Mex. (localities 9269, 9270, 9271), 115 to 140 feet above the base of the Fruitland formation. It is noteworthy that the species has not been recorded from any locality between Montana and New Mexico.

Physa reesidei Stanton, n. sp.

Plate LXXXIII, figures 12 and 13.

Shell large, stout, with very small depressed spire; surface sculpture not preserved.

Height 44 millimeters; greatest breadth about 32 millimeters; height of aperture almost equal to length of shell, and breadth about half the breadth of the shell.

This species seems to be sufficiently distinct to justify its description, even from the imperfect material at hand—eight more or less distorted casts, of which the best-preserved one is selected as type. Its nearest relative among American fossil forms appears to be *Physa felix* White, from the Laramie of Crow Creek, Colo.

Locality and position: About 200 feet above the base of the Fruitland formation at Bauer's locality 27, 17 miles south of San Juan River and 4 miles east of Chaco River, N. Mex. (locality 9285)

Physa sp.

Another species of Physa, smaller and much more slender than *P. reesidei*, is represented by two fragmentary specimens from Bauer's locality 22, near the base of the Fruitland formation, 12½ miles south of San Juan River and 1 mile east of Chaco River, N. Mex. (locality 9283).

Planorbis (Bathyomphalus) chacoensis Stanton, n. sp.

Plate LXXXIII, figures 14–16.

Shell small, consisting of about five very gradually increasing whorls; spire flat; whorls slightly rounded above, carinate on the periphery, broadly rounded from the carina to the margin of the umbilicus, which is nearly as broad as the last whorl; surface marked by relatively coarse lines of growth.

Greatest diameter 7 millimeters; height 3 millimeters; breadth of last whorl 2 millimeters.

This little species is evidently congeneric with *Planorbis* (*Bathyomphalus*) *kanabensis* White, from the so-called Laramie of the Kanab Valley, Utah. It appears to differ from White's species in its somewhat more rapidly increasing whorls and its more distinctly carinate periphery.

Locality and position: At Bauer's locality 22, near the base of the Fruitland formation, 12½ miles south of San Juan River and 1 mile east of Chaco River, N. Mex. (locality 9283).

PLATES LXXIX-LXXXIII.

PLATE LXXIX.

Ostrea glabra Meek and Hayden var. (p. 311).

FIGURES 1, 2. Upper valves.
3. Lower valve.
U. S. N. M., catalogue No. 32026.

Anomia gryphæiformis Stanton (p. 311).

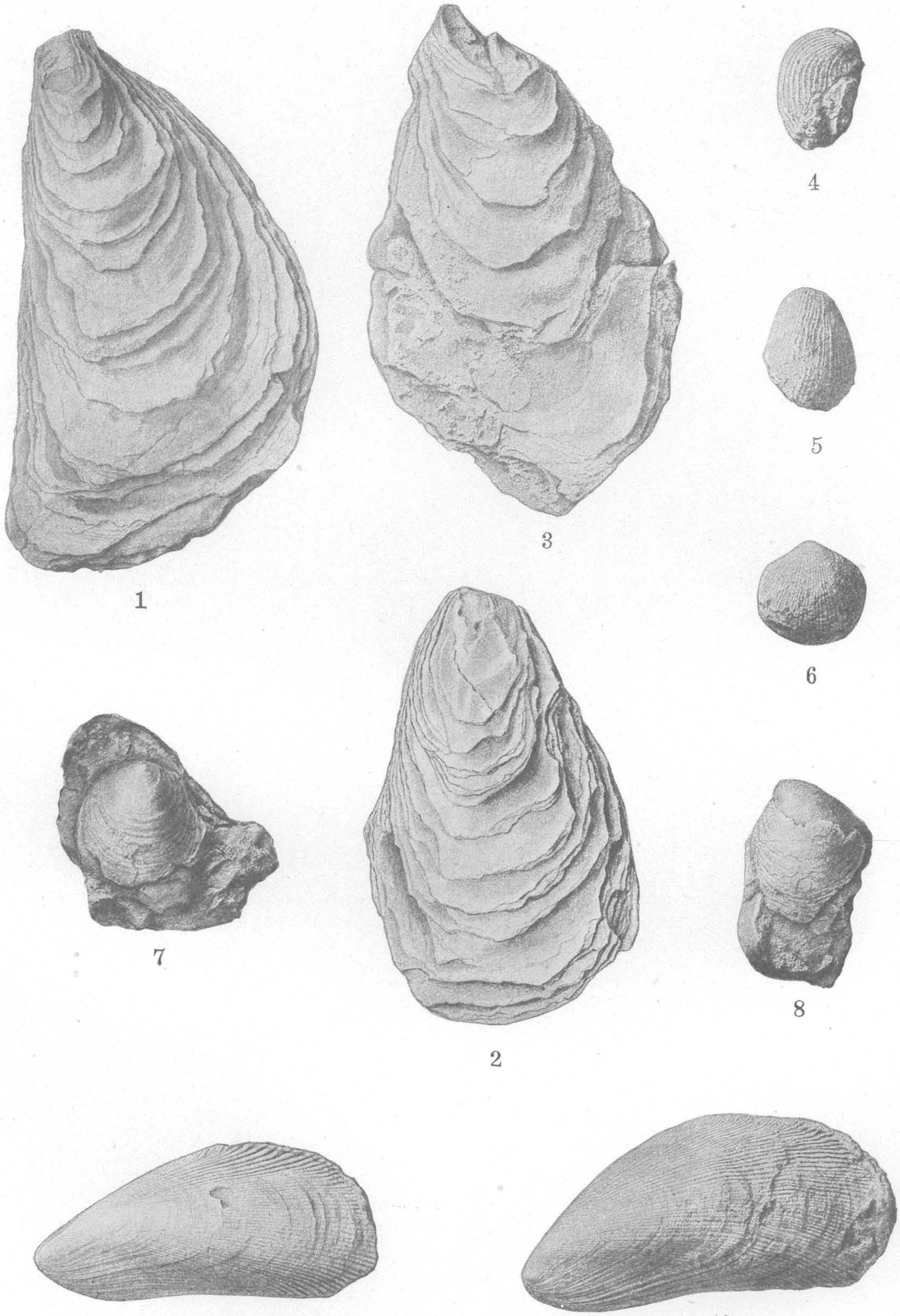
FIGURES 4, 5. Side and profile views of typical form.
6. Side view of broader, less convex specimen.
U. S. N. M., catalogue No. 32027.

Anomia gryphorhynchus Meek (p. 311).

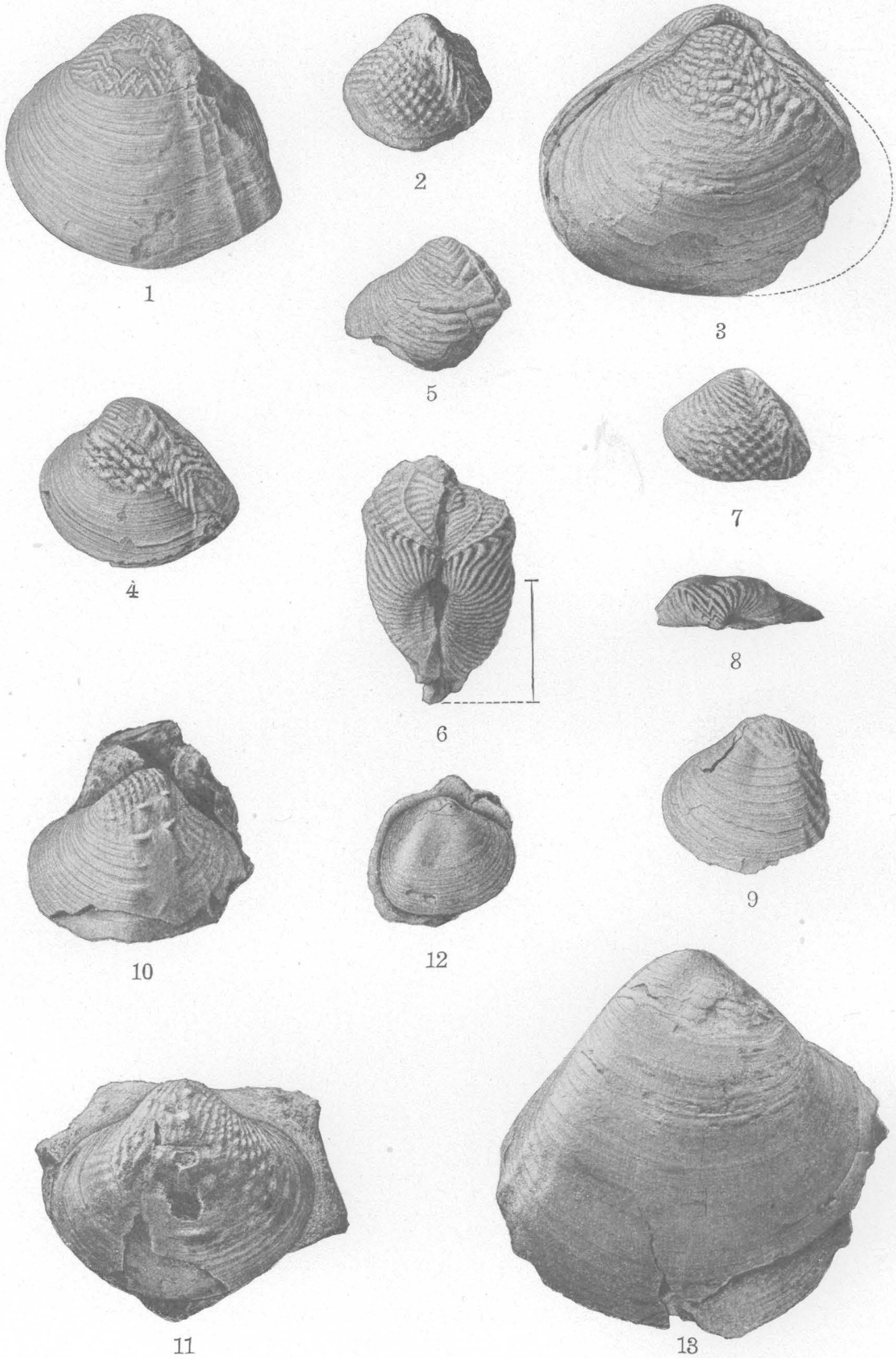
FIGURES 7, 8. Side views of two specimens varying in outline and convexity.
U. S. N. M., catalogue No. 32028.

Modiola laticostata (White) (p. 311).

FIGURES 9, 10. Left valves of two specimens varying in form and sculpture.
U. S. N. M., catalogue No. 32029.



NONMARINE CRETACEOUS INVERTEBRATES OF THE SAN JUAN BASIN.



NONMARINE CRETACEOUS INVERTEBRATES OF THE SAN JUAN BASIN.

PLATE LXXX.

Unio holmesianus White (p. 312).

FIGURES 1, 2. Type specimens from Black Buttes, Wyo., figured by White.
U. S. N. M., catalogue No. 9041.
3, 4. Specimens from T. 35 N., R. 7 W., Ignacio quadrangle, Colo.
U. S. N. M., catalogue No. 32030.
5. Fragmentary specimen, showing beak sculpture, from Amarillo Canyon, N. Mex.
U. S. N. M., catalogue No. 32031.
6, 7. Immature specimens, showing details of beak sculpture, from T. 35 N., R. 8 W., Ignacio quadrangle, Colo. Figure 6 is enlarged 2 diameters.
U. S. N. M., catalogue No. 32032.

Unio amarillensis Stanton (p. 313).

FIGURES 8, 9. Side and profile views of type.
U. S. N. M., catalogue No. 32033.

Unio gardneri Stanton (p. 314).

FIGURE 10. Left valve.
11. Right valve. Both from Ignacio quadrangle, Colo.
U. S. N. M., catalogue No. 32034.

Unio pyramidatoides Whitfield? (p. 313).

FIGURE 12. Small right valve.
13. Larger right valve with surface partly exfoliated.
U. S. N. M., catalogue No. 32035.

PLATE LXXXI.

Unio reesidei Stanton (p. 314).

FIGURE 1. Type specimen.
U. S. N. M., catalogue No. 32036.

Unio brachyopisthus White (p. 314).

FIGURE 2. Left valve of an elongate specimen from Amarillo Canyon, N. Mex.
U. S. N. M., catalogue No. 32037.
3. Right valve of typical form from Yellow Jacket Creek, Colo.
U. S. N. M., catalogue No. 32038.

Unio neomexicanus Stanton (p. 315).

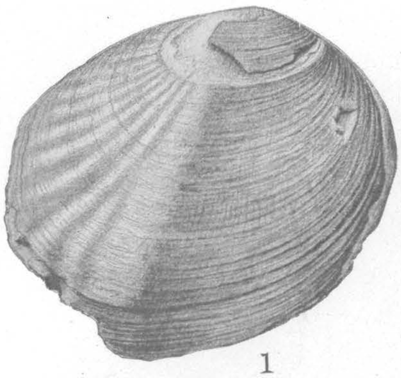
FIGURE 4. Left valve, slightly distorted by crushing.
5. Smaller left valve.
U. S. N. M., catalogue No. 32039.

Unio baueri Stanton (p. 315).

FIGURE 6. Type specimen, left valve.
U. S. N. M., catalogue No. 32040.

Unio brimhallensis Stanton (p. 315).

FIGURE 7. An imperfect right valve. Outline restored from specimen represented by Pl. LXXXII, fig. 1.
U. S. N. M., catalogue No. 32041.



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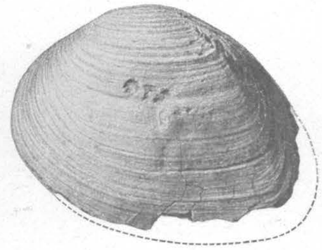

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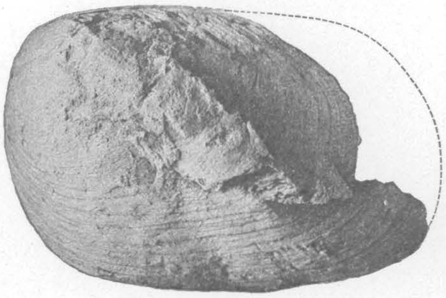

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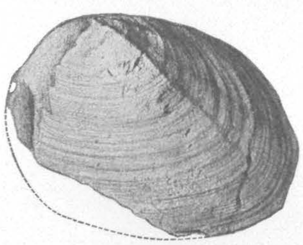

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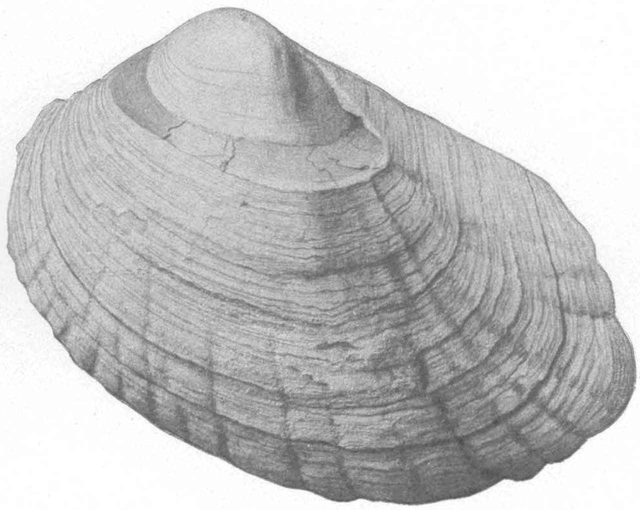

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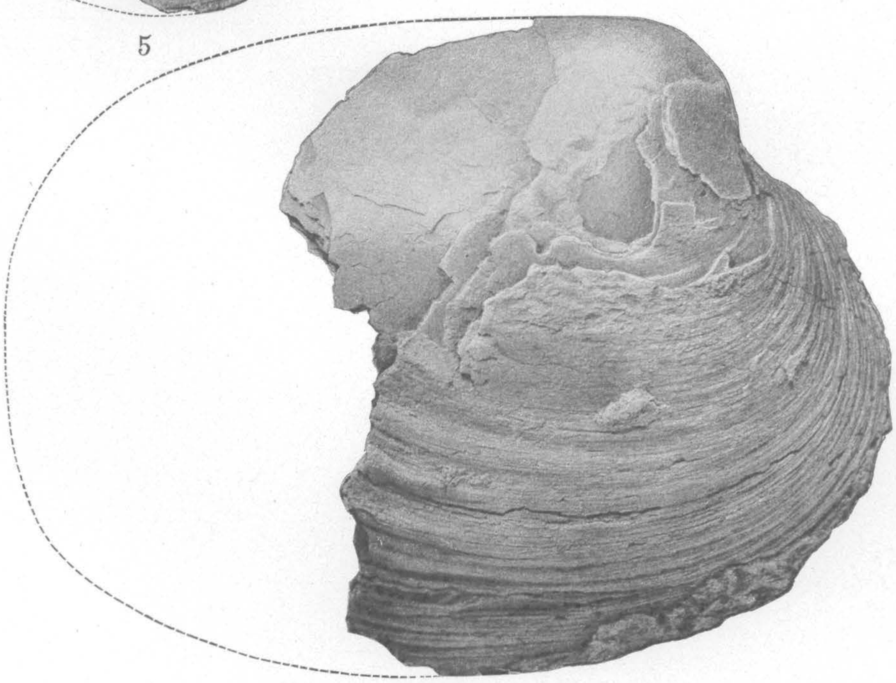

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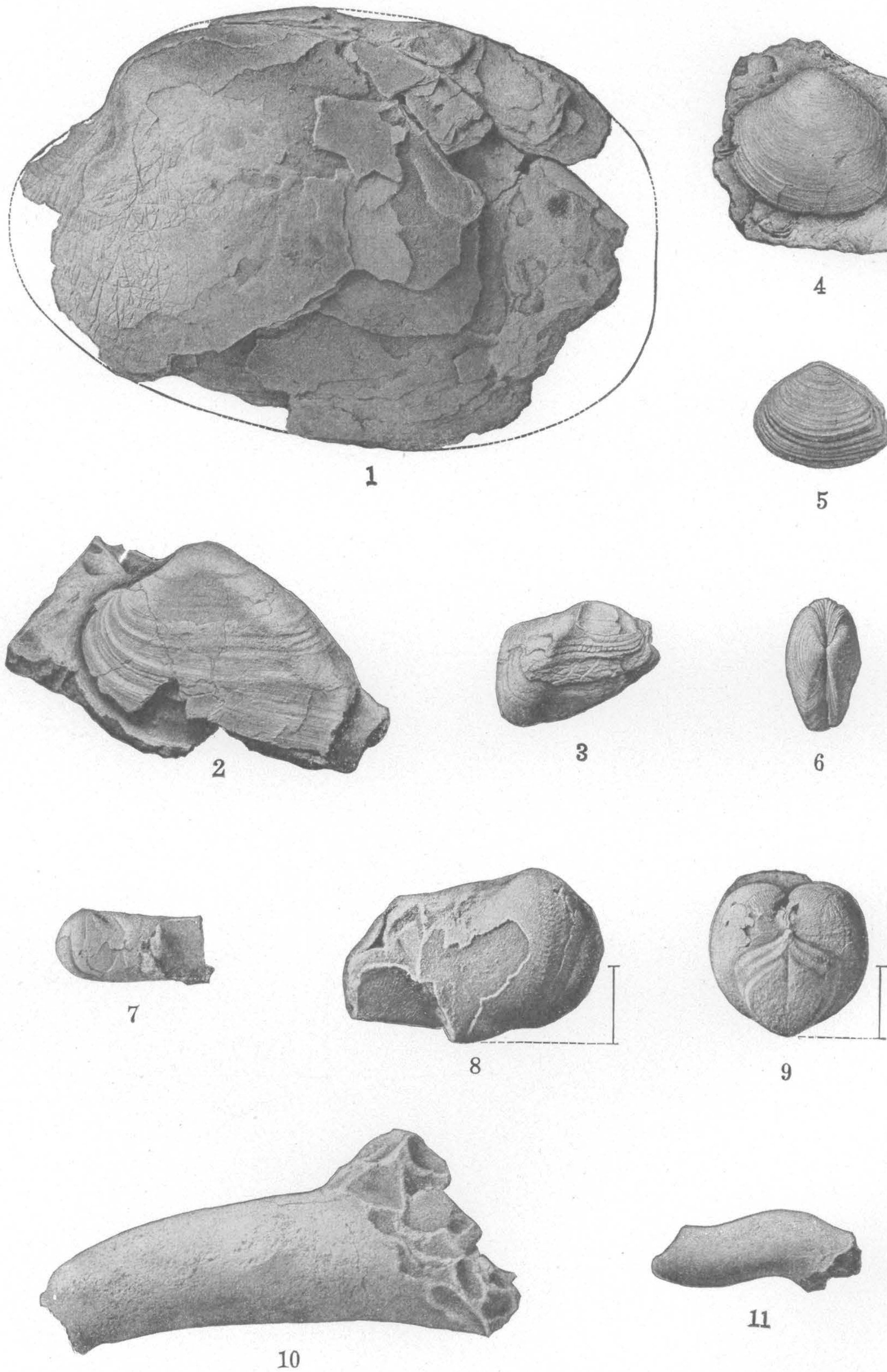
NONMARINE CRETACEOUS INVERTEBRATES OF THE SAN JUAN BASIN.



NONMARINE CRETACEOUS INVERTEBRATES OF THE SAN JUAN BASIN.

PLATE LXXXII.

Unio brimhallensis Stanton (p. 315).

FIGURE 1. An exfoliated left valve.
U. S. N. M., catalogue No. 32041.

Unio sp. cf. U. primævus White (p. 315).

FIGURE 2. Imperfect left valve, distorted by crushing.
U. S. N. M., catalogue No. 32042.
3. Fragment showing umbonal portion of right valve.
U. S. N. M., catalogue No. 32043.

Corbicula cytheriformis Meek and Hayden (p. 316).

FIGURE 4. Small left valve.
U. S. N. M., catalogue No. 32044.

Corbula chacoensis Stanton (p. 316).

FIGURES 5, 6. Left side and profile views of type.
U. S. N. M., catalogue No. 32045.

Teredina neomexicana Stanton (p. 317).

FIGURE 7. Left side of specimen retaining part of tube.
8, 9. Right side and front views of another specimen, × 2.
10, 11. Casts of tubes believed to belong to this species. U. S. N. M., catalogue No. 32046.

PLATE LXXXIII.

Neritina baueri Stanton (p. 317).

FIGURES 1, 2. Front and back views of type.
U. S. N. M., catalogue No. 32047.
3, 4. Front and back views of smaller specimen.
U. S. N. M., catalogue No. 32048.

Campeloma amarillensis Stanton (p. 318).

FIGURE 5. Front view of large type.
6. Back view of smaller specimen.
U. S. N. M., catalogue No. 32049.

Goniobasis? subtortuosa (Meek and Hayden) (p. 319).

FIGURE 7. Front view of large specimen.
8. Back view of smaller specimen.
U. S. N. M., catalogue No. 32050.

Tulotoma thompsoni White (p. 318).

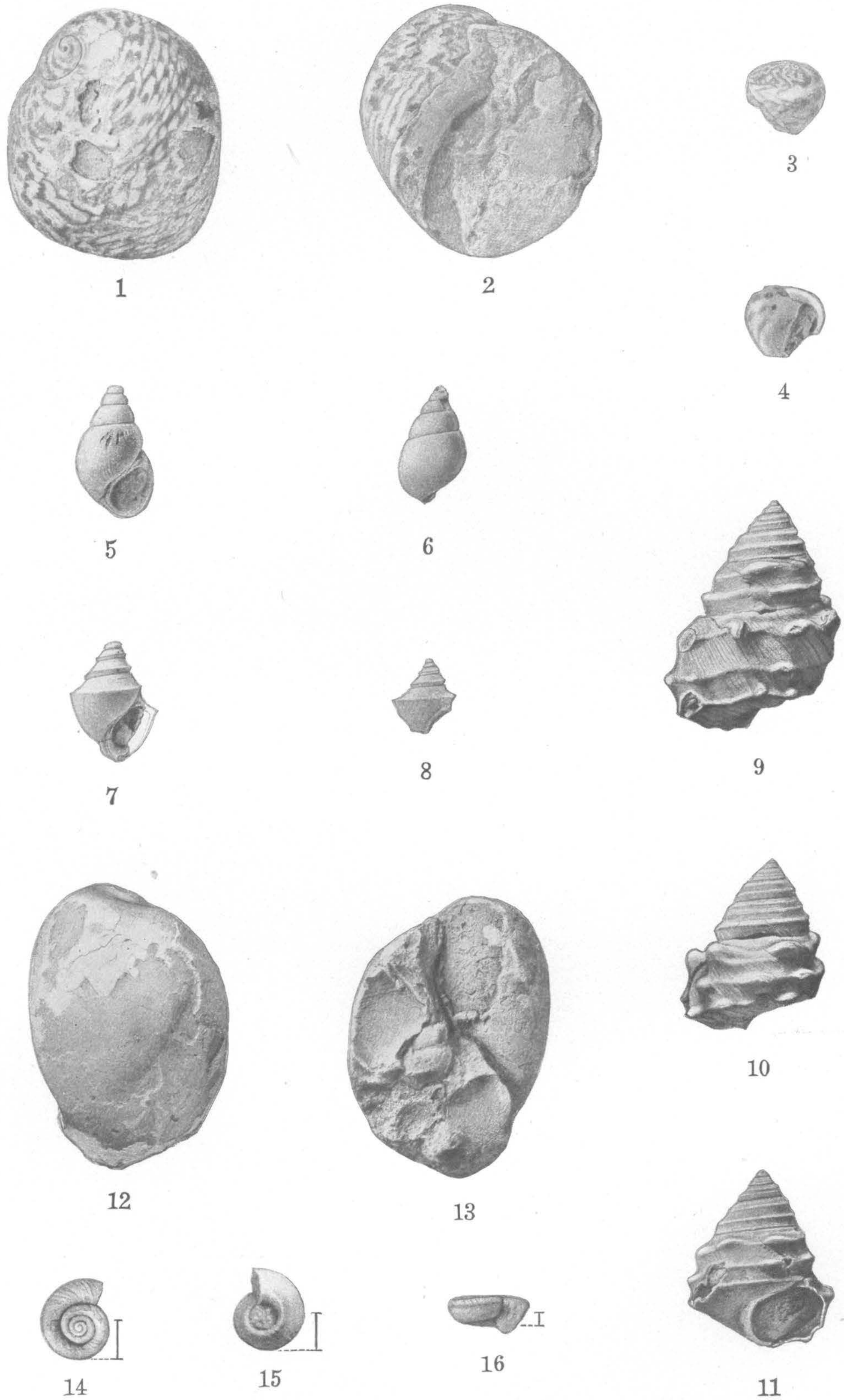
FIGURES 9, 10. Back views of two specimens.
11. Front view of another specimen.
U. S. N. M., catalogue No. 32051.

Physa reesidei Stanton (p. 319).

FIGURES 12, 13. Back and front views of slightly distorted cast.
U. S. N. M., catalogue No. 32052.

Planorbis (Bathyomphalus) chacoensis Stanton (p. 319).

FIGURES 14–16. Top, bottom, and front views of the type, × 2.
U. S. N. M., catalogue No. 32053.



NONMARINE CRETACEOUS INVERTEBRATES OF THE SAN JUAN BASIN.

4. FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.

By F. H. Knowlton.

HISTORICAL SUMMARY.

San Juan County, in the extreme northwest corner of New Mexico, comprises but a small portion of the larger more or less clearly defined structural area known as the San Juan Basin. Certain structural elements, particularly the upper series of coal-bearing rocks, form a more or less continuous rim around this basin and dip toward the center, where, however, they are deeply buried.

As the object of the present study is to ascertain the bearing of the fossil plants on the age of this series of coal-bearing and related rocks, it is desirable to give first a brief historical setting for the geologic facts here set forth. It is not necessary in this connection, however, to go further back than the beginning of the time embraced within the history of the so-called "Laramie problem"—that is, to about 1875.

The San Juan district was studied by W. H. Holmes,[1] of the Hayden Survey, during the field season of 1875. The results of his studies of the rocks in the valley of San Juan River are displayed in a generalized section in Plate XXXV of his report. The uppermost member of this section is referred to the Wasatch and is divided into two parts, the lower of which is the Puerco marls of Cope, now included in the Puerco and Torrejon formations. Immediately below the Puerco marls is the so-called "Upper coal group," made up of 800 feet of soft sandstones and marls, which is called Laramie ?. This in turn rests on massive sandstone 120 feet thick, called the Pictured Cliffs group, and on the evidence of invertebrates was referred to the Fox Hills unit.

Except for the preparation of a number of economic reports on the coal of this region, little systematic geologic work was done in the region until 1899, when Cross [2] established the units of the Upper Cretaceous section, which subsequently have been so widely identified in Colorado, Wyoming, and Montana. These units, in ascending order, are the Mancos shale, Mesaverde formation, and Lewis shale. Concerning the Lewis shale Cross wrote as follows:

> Above the Mesaverde formation occurs another formation of clay shale, reaching an observed thickness of nearly 2,000 feet, which is very much like the Mancos shale but contains fewer fossils. The only identifiable form thus far found in this shale occurs also in the Mancos shale, so that this division is still apparently below true Fox Hills. This formation is called the Lewis shale.

Continuing, Cross says:

> Still above the Lewis shale is a second series of sandstones, shales, and clays, bearing some resemblance to the Mesaverde formation but differing in detail. The lowest member of this complex is the "Pictured Cliff sandstone" of Holmes's San Juan section, which he placed in the Fox Hills upon the evidence of invertebrate remains. The remainder was referred to the Laramie, but without fossil evidence. The present survey has failed to bring to light valid ground for assigning any of the beds in question to the Laramie, while there is some reason to believe that more than the lower sandstone belongs to the Montana group.

In 1905 Schrader [3] made a reconnaissance examination of the Durango-Gallup coal field in which he adopted the stratigraphic classification established by Cross and described the uppermost coal-bearing sandstone as Laramie ?, though he presented no fossil evidence.

In 1906 more detailed examinations were made in the region by Taff and Shaler. Taff [4] studied the Durango coal district, which lies just off the southern foothills of the San Juan and La Plata mountains, and in his report the upper coal-bearing rocks here under consideration were referred without question to the Laramie, though he gave no details as to the reason for this reference. Shaler's report [5] deals with that part of the Durango-Gallup field lying

[1] Holmes, W. H., Geological report on the San Juan district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1875, p. 241, 1877.

[2] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899.

[3] Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 285, pp. 241-258, 1906.

[4] Taff, J. A., The Durango coal district, Colo.: U. S. Geol. Survey Bull. 316, pp. 321-337, 1907.

[5] Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado: Idem, pp. 376-426.

west of longitude 107° 30′. The beds here discussed were also referred by Shaler to the Laramie without qualification, on the basis, it is stated, of fossils studied by T. W. Stanton and F. H. Knowlton, though the evidence is not presented in detail. On looking over the original reports on the plants collected by Shaler and others in this region, I find that they were few and fragmentary collections only, and the tendency was to regard them as mainly older than Laramie.

The status of the "Laramie" in the region under consideration was so well summed up by Lee [1] in 1912 that his statement is quoted entire as follows:

The "Laramie" formation occurs within the area described in this paper only in the San Juan Basin. It is more than 1,000 feet thick in the southern rim of the basin but is thinner in the eastern rim, probably due to post-Cretaceous erosion. At Dulce it is only 225 feet thick. The formation lies conformably on Lewis shale and probably for this reason more than any other has been called Laramie, although Dr. Cross several years ago called attention to the fact that investigation had "failed to bring to light valid ground for assigning any of the beds in question to the Laramie, while there is some reason to believe that more than the lower sandstone belongs to the Montana group." Since that time a considerable number of fossils, both of invertebrates and of plants, have been collected from these beds in the Durango region. The base of the formation—the Pictured Cliff sandstone—contains marine invertebrates, and the lower part of the coal-bearing rocks above this sandstone contains brackish-water invertebrates, several of which occur in the Mesaverde of other fields. But higher in the formation the rocks contain fresh-water invertebrates which Dr. Stanton regards as Laramie and fossil plants which Dr. Knowlton regards as older than Laramie. The fossil plants have been given in the table * * * and from this table as well as from the accompanying statement by Dr. Knowlton [see below] it will be seen that the flora differs but little from that of the Mesaverde farther to the south. The name "Laramie" is here used for this formation not because the writer wishes to argue for the Laramie age of the rocks, but because the name is in use and because in this paper the writer is intentionally avoiding the introduction of new names for rock formations. It must be noted, however, that while the formation is called "Laramie" it contains a flora which denotes Montana age, having nothing in common with the Laramie flora of the Denver Basin.

The statement by me to which Lee alludes is as follows:

Near Dulce, N. Mex., and near Durango, Colo., there have been obtained two collections of plants from above the Lewis shale in coal-bearing rocks that have been referred to the so-called "Laramie" of this region. These collections are very full and embrace a number of easily recognized species; hence their identification is satisfactory and complete. These collections prove clearly that these beds do not belong to the Laramie, since, so far as known to the writer, not a single species there present has been found in beds of this age. On the other hand, the plants indicate beyond question that they belong to the Montana, there being, for instance, *Ficus speciosissima*, Ficus sp. (narrow, three-nerved type), Ficus sp., type of *F. lanceolata*, a palm, etc., which link them with the Mesaverde floras to the south and the beds already discussed in the Raton Mesa region. Associated with these, however, and tending to give them a slightly higher position, though still within the Montana, are such forms as Brachyophyllum, Cunninghamites, Geinitzia, Sequoia, etc., all of which are beyond doubt Montana types not found in the Laramie.

A number of collections were made by J. H. Gardner in the Ignacio quadrangle, east of Durango, Colo., from beds regarded as the Laramie of that area. The plants in these collections, almost species by species, are identical with the forms from near Dulce and near Durango, and I have no hesitation in saying that they occupy the same stratigraphic position and are of the same age, viz, Montana.

It now remains to consider certain dinosaur-bearing beds first reported near Ojo Alamo, N. Mex., which may have a bearing on the "Laramie" of the San Juan Basin region. In 1908 James H. Gardner, then of the United States Geological Survey, found reptilian vertebrate remains near the head of Coal Creek, 1 mile southeast of Ojo Alamo, "in variegated sands, shales, and conglomerates, indisputably above the unconformity at the top of the Laramie.[2] These remains were studied by C. W. Gilmore, who states that this fauna "appears to represent a typical fauna of the so-called Laramie or better Ceratops beds."

It appears that dinosaur remains had been known at the Ojo Alamo locality as early as 1902, but it was not until 1904 that a systematic attempt was made to collect them. In this year Barnum Brown, of the American Museum of Natural History, made a reconnaissance trip to the locality and obtained "a small but interesting collection of fossils." These, however, were not described in print until 1910.[3] Concerning the stratigraphic relations of these beds Brown says:

Less than a mile south of the store at Ojo Alamo the Puerco formation rests unconformably on a conglomerate

[1] Lee, W. T., Stratigraphy of the coal fields of northern New Mexico: Geol. Soc. America Bull., vol. 23, pp. 607-608, 1912.

[2] Gardner, J. H., in Knowlton, F. H., The stratigraphic relations and paleontology of the "Hell Creek beds," "Ceratops beds," and equivalents, and their reference to the Fort Union formation: Washington Acad. Sci. Proc., vol. 11, p. 323, 1909.

[3] Brown, Barnum, The Cretaceous Ojo Alamo beds of New Mexico, with description of the dinosaur genus Kritosaurus: Am. Mus. Nat. Hist. Bull., vol. 28, pp. 267-274, 1910.

that is composed of red, gray, yellow, and white pebbles. The position of these beds is below what may be called the type of the Puerco or basal Eocene. * * * Below the conglomerate there is a series of shales and sandstones, evenly stratified and usually horizontal, in which there is much less cross-bedding than commonly occurs in the Laramie of the northern United States.

The shales below the conglomerates that contain numerous dinosaur and turtle remains I shall designate as the Ojo Alamo beds. They are estimated to be about 200 feet thick, but owing to lack of time I was unable to determine their relations to the underlying formations.

Also in 1910 appeared a paper by Gardner[1] that involved incidentally the beds under discussion. He records the Puerco as resting unconformably on the underlying beds, as Brown had reported, and he states that at Ojo Alamo he "obtained dinosaurs from beds unconformably above the 'Laramie' and below the Wasatch." These beds are, of course, the Ojo Alamo beds of Brown.

From the preceding brief statements it appears that for more than 40 years the upper coal-bearing rocks of the San Juan Basin have been regarded more or less definitely as of Laramie age, though during quite half of this time there has been growing an undercurrent of opinion that the beds may be older than the Laramie. The object of the present study is to ascertain the bearing of the fossil plants on this question, and it may be stated here that the plants appear fully to sustain the opinion that the beds are older than the Laramie.

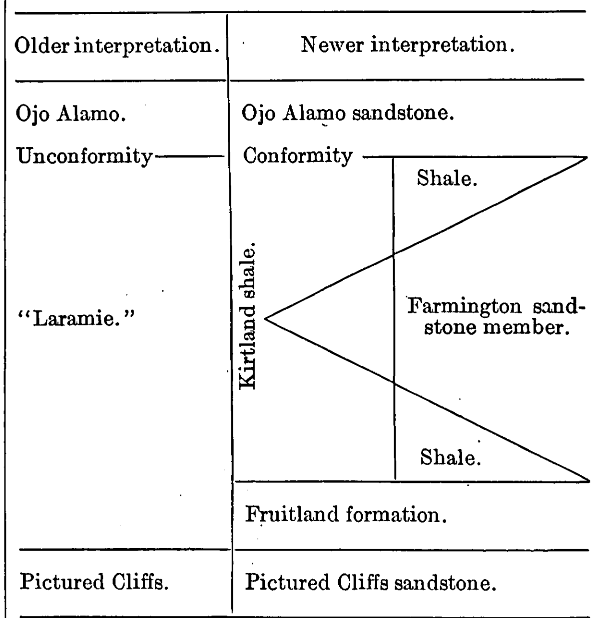
The fossil plants upon which the present report is based were obtained by C. M. Bauer during his geologic studies of the season of 1915 in that portion of the San Juan Basin embraced within San Juan County, N. Mex. The stratigraphic results of his investigations are set forth at length in the paper by Bauer,[2] and in the present connection it is necessary only to give them in brief outline. In that portion of the coal-bearing and associated rocks previously referred to as the "Laramie" of that region Bauer has recognized two lithologic units. The lower of these units, called the Fruitland formation, is about 300 feet thick and includes the coal-bearing beds. Above it is a series of shales, called the Kirtland shale, with an intercalated sandstone, the Farmington sandstone member, and the whole formation has a maximum thickness of nearly 1,200 feet.

[1] Gardner, J. H., The Puerco and Torrejon formations of the Nacimiento group: Jour. Geology, vol. 18, pp. 702-741, 1910.

[2] U. S. Geol. Survey Prof. Paper 98, pp. 274-275 (Prof. Paper 98-P).

Above the Kirtland shale, without observed stratigraphic break, is the Ojo Alamo sandstone, which Bauer thinks should be grouped with the underlying Kirtland and Fruitland formations.

A graphic presentation of the older and newer views is given below:



THE FLORA.

The material on which the present report is based comprises 20 collections, of which 15 are from the Fruitland formation, 3 from the Kirtland shale (2 from the extreme top and 1 from the base of the formation), and only 1 from the Ojo Alamo sandstone. The bulk of the material comes from the lower or coal-bearing portion of the section, and much of this is preserved on a red baked shale, indicating proximity to coal.

The material in the single collection from the Ojo Alamo beds is so fragmentary that it can not be identified with satisfaction. It includes portions of a large leaf of unknown affinity, a small willow-like leaf, and a large leaf that appears to be an Aralia of the type of *Aralia notata* Lesquereux, a species very abundant and widely distributed in the Fort Union formation. Nothing like this has been noted in the underlying beds, and to a certain extent it argues for the Tertiary age of the Ojo Alamo beds, though obviously the evidence is not strong. For the present, therefore, the dictum based on the evidence of the fossil vertebrates that these beds can not be separated from the underlying beds must be accepted, though the writer can not escape the impression that they may ultimately be shown to be of Tertiary age.

Below is a complete list of the forms represented in the collections from the Fruitland and Kirtland formations.

Asplenium neomexicanum Knowlton, n. sp.
Onoclea neomexicana Knowlton, n. sp.
Anemia hesperia Knowlton, n. sp.
Anemia sp.
Sequoia reichenbachi (Geinitz) Heer.
Sequoia obovata? Knowlton.
Geinitzia formosa Heer.
Sabal montana Knowlton.
Sabal? sp.
Myrica torreyi Lesquereux.
Myrica? neomexicana Knowlton, n. sp.
Salix baueri Knowlton, n. sp.
Salix sp. *a* Knowlton.
Quercus baueri Knowlton, n. sp.
Ficus baueri Knowlton, n. sp.
Ficus curta? Knowlton.
Ficus prætrinervis Knowlton.
Ficus leei Knowlton.
Ficus prælatifolia Knowlton, n. sp.
Ficus sp.
Ficus rhamnoides Knowlton.
Ficus squarrosa Knowlton.
Ficus sp.
Ficus eucalyptifolia? Knowlton.
Laurus baueri Knowlton, n. sp.
Laurus coloradensis Knowlton.
Nelumbo sp.
Heteranthera cretacea Knowlton, n. sp.
Pistia corrugata Lesquereux.
Leguminosites? neomexicana Knowlton, n. sp.
Pterospermites undulatus Knowlton.
Pterospermites neomexicanus Knowlton, n. sp.
Pterospermites sp.
Ribes neomexicana Knowlton, n. sp.
Carpites baueri Knowlton, n. sp.
Phyllites petiolatus Knowlton, n. sp.
Phyllites neomexicanus Knowlton, n. sp.
Unassigned plant (a).
Unassigned plant (b).

The above list comprises 40 forms, of which 6 are so fragmentary that they have not been given specific names, 2 have not been assigned, even generically, 16 are regarded as new to science, leaving 16 species known previously in other areas.

Although new species as such have little value in fixing the age of the rocks in which they occur, it not infrequently happens that important and far-reaching conclusions may be drawn from a consideration of their obviously close relation with species whose stratigraphic relations are known. Thus the species described as *Asplenium neomexicanum* is not to be distinguished from the fragment described as Asplenium sp. Knowlton, from the Mesaverde of Dutton Creek, Laramie Plains, Wyo. *Onoclea neomexicana* belongs to a very long lived type, which, it was previously supposed, began in the Fort Union and is still living. The present form carries the type much further back. *Anemia hesperia* is not closely related to any previously described fossil species from this country. *Myrica? neomexicana* is so poorly represented that its generic reference has been questioned, and hence its relationship is obscured. The specimen of *Salix baueri* is also poorly preserved as regards nervation and is of little value in fixing its affinity. *Quercus baueri* is most closely related to an unpublished species from the Vermejo formation of southern Colorado, differing in its slightly smaller size and less prominent teeth. *Ficus baueri* is, in a way, of the type of *Ficus denveriana*, a large Denver species, but it differs very markedly in nervation and is not considered to be closely related to that species. *Ficus prælatifolia* is most nearly related to *Ficus planicostata latifolia*, a form first made known from Black Buttes, Wyo., but later recorded from a number of horizons, including Montana and Laramie. *Laurus baueri* is of the type of *Laurus socialis*, a Tertiary form, but differs in nervation as well as in size. *Heteranthera cretacea* belongs to a living type that has not before been detected in a fossil state. The single minute leaflet described under the name *Leguminosites? neomexicana* is so small and obscure that its affinity can not be established. *Pterospermites neomexicanus* is probably most closely related to *Pterospermites undulata* of Point of Rocks, Wyo. *Ribes neomexicana* is without known close relations among fossil forms. The species of Carpites and Phyllites have been designated by these nondescript names because they are without recognized affiliations.

The species common to the Fruitland and Kirtland formations and the Laramie formation of the Denver Basin are *Sequoia reichenbachi, Sabal montana, Myrica torreyi*, and *Ficus prætrinervis*. In working up the flora of the Laramie of the Denver Basin of Colorado it has been found that this flora embraces approximately 125 species, of which nine are known to be common to the Montana. As all four of the above-named species are included in the nine common to the Laramie and Montana, it follows they can not be used as an argument for the Laramie age of the Fruitland and Kirtland formations, because without collateral data it would be impossible to decide their age in the San Juan Basin. As a matter of fact, while these four species are known to occur in the Laramie, their principal distribution is in beds older than Laramie. Thus, *Sequoia reichenbachi* is known to range from the upper part of the Jurassic entirely through the Cretaceous, being perhaps most abundant, at least as regards individuals, in the middle Montana. *Sabal montana* is the principal species of palm in the Montana. *Myrica torreyi* was described originally from Black Buttes, Wyo., but it has since been demonstrated to be most abundant and widely distributed in the Montana. *Ficus prætrinervis* was first found in the Vermejo formation of Colorado and New Mexico, where at certain localities it is exceedingly abundant.

The species common to the Fruitland and Kirtland formations and the Montana group are as follows:

*Asplenium neomexicanum.
*†Sequoia reichenbachi.
*†Sequoia obovata?
*†Geinitzia formosa.
*†Sabal montana.
*†Myrica torreyi.
†Salix sp. *a*.
†Ficus curta?
†Ficus prætrinervis.
†Ficus leei.
*Ficus rhamnoides.
*Ficus squarrosa.
†Ficus eucalyptifolia?
†Laurus coloradensis.
*Pistia corrugata.
*†Pterospermites undulatus.

The species in the above list that are marked with an asterisk (*) are found also in the Montana of Wyoming, mainly at Point of Rocks; those marked with a dagger (†) are found in the Vermejo of Colorado and New Mexico.

Of the 40 forms making up the known flora of the Fruitland and Kirtland formations, 16 have been found in other areas, and the above list brings out the fact that no less than 15 of these forms are known to occur in the Montana. A further analysis of the list shows that 12 of the 15 forms occur in the Vermejo formation of Colorado and New Mexico, 10 occur in the Mesaverde, or rocks of about this age, in Wyoming and elsewhere, and 6 species are common to both these areas. On the basis of this showing the conclusion seems justified, therefore, that the Fruitland and Kirtland formations are of Montana age.

Family POLYPODIACEÆ.

Asplenium neomexicanum Knowlton, n. sp.

Plate LXXXIV, figures 5–9.

Asplenium sp. Knowlton, U. S. Geol. Survey Bull. 163, p. 20, pl. 3, fig. 11, 1900.

Frond at least firm in texture; outline of whole frond not known but apparently simple or once forked, base abruptly rounded and slightly cordate, apex abruptly narrowed to an acuminate point; margin finely toothed, the teeth small and apparently spinose; stipe slender, its length not known but at least 6 centimeters; nervation very distinct, consisting of a rather strong midvein and numerous veins at an angle of emergence of about 45°, usually forking at or very near the base and occasionally once above, the veins or nearly all of them entering the teeth; sori long, narrowly linear, attached to the upper side of the veins.

This very interesting species is represented by about a dozen fragments, five of which are here figured. Although none is of sufficient completeness to show the outline of the whole frond, they include parts that give what seems to be a fairly complete knowledge of its appearance. Two examples (figs. 8 and 9) show the configuration of the base and a portion of the slender stipe, and two (figs. 5 and 6) show the apical portion, figure 5 being particularly complete to the tip. It appears that as a rule the rachis forks at an angle of approximately 45° a very short distance above the base of the frond, producing two broad, probably short, obtusely pointed lobes. In the specimen shown in figure 8 (right-hand leaf), however, there is no evidence of forking within its preserved length of 5 centimeters, and whether it was forked at a still higher point or was entire can not be determined. The marginal teeth may be noted at a number of points in the specimens figured but are especially distinct in figure 6.

The nervation is very distinct and is well shown in all the specimens. Most of the nerves fork at the base and some of them also above the middle, but here and there one may be noted that is simple and unforked throughout. Most of the nerves enter the teeth.

Several of the specimens, notably those illustrated in figures 7 and 9, show the fruit, though this fact was not detected until it was pointed out by W. R. Maxon, of the United States National Museum, to whom the specimens were shown. The sori are apparently somewhat immature, being very long and narrowly linear, hardly more than doubling the normal thickness of the vein.

This species undoubtedly is most nearly related to *Asplenium hemionitis* Linné, now living in Spain, Portugal, and the adjacent Atlantic islands. *A. hemionitis* is usually five-lobed, having a large triangular acute terminal lobe and two shorter similar acute lateral lobes which are bluntly or sometimes acutely lobed at the base; the basal sinus is deep and rounded, and the basal lobes overlap the stipe.

Occurrence: Kirtland shale, 3 inches below base of Ojo Alamo sandstone, 1½ miles east-northeast of Pina Veta China, San Juan County, N. Mex. Lot 40 (6966).

Onoclea neomexicana Knowlton, n. sp.

Plate LXXXIV, figures 1, 2.

Size and outline of whole frond unknown, though evidently it was rather large and at least bipinnatified; main rachis thin, ridged; pinnæ apparently alternate, rather widely spaced, apparently connected by a broad wing; pinnæ short, broad, deeply cut into several lobes, those near the base rather obtuse and provided with a few teeth, the outer lobes acute and entire; nervation very strongly marked, reticulated throughout, the reticulations or areas inclosed by the veins somewhat irregular but in general about four times longer than broad.

The available material representing this form is so scanty and imperfectly preserved that ordinarily to attempt a characterization of it would hardly be worth while, but it is so clear as far as it goes that it can undoubtedly be recognized if found in the future, and moreover it furnishes a valuable biologic step in the interpretation of the geologic history of this genus. As may be seen from the figures, which represent all but a few inconsequential fragments, it is impossible to form any adequate idea as to the size of the whole frond, as there is no means of knowing what part of the frond is represented. So far as can be made out the pinnæ are alternate, a considerable distance apart, and apparently connected by a broad wing. The best-preserved pinna was about 4.5 centimeters long and at least 2.5 centimeters wide. It is cut into four or more lobes having rather large teeth. The other figured specimen is probably the tip of a pinna, but it may be the extreme tip of the whole frond. It is cut into large, sharp-pointed lobes.

The nervation, as may be seen from the figures, is very distinct. It is completely anastomosing, the inclosed areas being somewhat irregular, though in general they are three or four times longer than broad. No trace of the fruiting frond was detected.

This species is undoubtedly most closely related to the living *Onoclea sensibilis* Linné, which, so far as can be determined, has also been found abundantly and widely distributed, in a fossil state, in the Fort Union formation. The fossil form, under the name *Onoclea sensibilis fossilis*, was first described and figured by Newberry[1] from specimens obtained at Fort Union, on Yellowstone River near the Montana-North Dakota line. This form and *Onoclea neomexicana* are so close together that with the material available it is not easy to point out essential differences between them. It appears, however, that in *Onoclea neomexicana* the pinnæ are shorter and relatively more deeply cut into lobes, which are themselves more or less toothed. The nervation is more completely reticulated throughout than in *Onoclea sensibilis fossilis*, but more and better preserved material must be available before it will be possible to determine definitely its distinctness or identity.

Occurrence: Kirtland shale, 3 inches below base of Ojo Alamo sandstone, 1½ miles east-northeast of Pina Veta China, San Juan County, N. Mex. Lot 40 (6966).

Family SCHIZIACEÆ.

Anemia hesperia Knowlton, n. sp.

Plate LXXXIV, figure 3.

Fronds presumably dimorphous; sterile frond roughly deltoid, 2.5 centimeters long, 3 centimeters broad, dipinnate, the rachis slender, pinnæ three or four pairs, alternate, lanceolate, decreasing toward the apex; pinnules confluent, cuneate, erose-dentate at apex; nerves few, slender, at an acute angle, once or twice forked; fertile frond not known.

[1] Newberry, J. S., New York Lyceum Nat. Hist. Annals, vol. 9, p. 30, 1868; U. S. Geol. Survey Mon. 35, p. 8, pl. 23, fig. 3; pl. 24, figs. 1-5, 1898.

The little specimen figured is all that was found of this form. It represents the upper portion of the frond, but whether it is the whole frond or a mere fragment can not be determined. From its apparent affinities it seems probable that the species was dimorphous, and that this specimen is only the sterile portion, the fertile frond remaining unknown.

Anemia hesperia finds its closest affinity with the living species of the group including *Anemia wrightii* Baker, *Anemia cicutaria* Kunze, and *Anemia cuneata* Kunze. These are all natives of Cuba and are found growing in crevices of rocks along shaded rivers.

Occurrence: Fruitland formation, about 10 miles south of Jewett and 2½ miles east of Chaco River, San Juan County, N. Mex. Lot 14 (6947).

Anemia sp.

Plate LXXXIV, figure 4.

The genus Anemia is very widely distributed both areally and vertically, but it rarely happens that specimens are well enough preserved to convey any adequate knowledge of the whole frond. The present material is so fragmentary that it does not admit of satisfactory identification. The specimen figured is sufficient to show clearly that it belongs to this genus, but beyond that no judgment can be ventured. It was evidently a large species, with pinnæ cut deeply into deltoid, very finely toothed lobes. The nervation is of the usual type.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 76 (6953).

Family PINACEÆ.

Sequoia reichenbachi (Geinitz) Heer.

Araucarites reichenbachi Geinitz, Charakteristik der Schichten und Petrefacten des sächsisch-böhmischen Kreidegebirges, pt. 3, p. 98, pl. 24, fig. 4, 1842.

Sequoia reichenbachi (Geinitz) Heer, Flora fossilis arctica, vol. 1, p. 83, pl. 43, figs. 1d, ab, 5a, 1868.

Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 6, p. 51, pl. 1, figs. 10–10b, 1874; U. S. Geol. Survey Mon. 17, p. 35, pl. 2, fig. 4, 1892.

The collections contain a few poorly preserved examples that are merely of sufficient value to indicate the presence of this widely spread species.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. In clinker above highest coal. Lot 75 (6956).

Sequoia obovata? Knowlton.

Sequoia obovata Knowlton, U. S. Geol. Survey Prof. Paper 101, p. —, pl. 30, fig. 7 (in press).

Sequoia brevifolia Heer, Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 365 [1876]; Ann. Rept. for 1874, p. 298 [1876]; Tenth Ann. Rept., for 1876, p. 500 [1878]; U. S. Geol. Survey Terr. Rept., vol. 7, p. 78, pl. 61, figs. 25–27, 1878.

Knowlton, U. S. Geol. Survey Bull. 163, p. 27, pl. 4, figs. 1–4, 1900.

In the present collections from the San Juan Basin is a single small, poorly preserved specimen that is clearly a Sequoia and from the few leaves retained appears to belong to this species. That this may be so is rendered likely by the fact that characteristic and well-identified specimens have previously been collected in this same region.

Occurrence: Fruitland formation, Hunters Wash, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 78 (6952).

Geinitzia formosa Heer.

Plate LXXXV, figure 3.

Geinitzia formosa Heer, Kreideflora von Quedlinburg: Schweiz. Gesell. Neue Denkschr., vol. 24, p. 6, pl. 1, fig. 9; pl. 2, 1871.

Newberry, U. S. Geol. Survey Mon. 26, p. 51, pl. 9, fig. 9, 1876.

Knowlton, U. S. Geol. Survey Bull. 163, p. 28, pl. 5, figs. 1–2, 1900; U. S. Geol. Survey Prof. Paper 101, p. —, pl. 31, figs. 1–3 (in press).

The figured specimen is a fragment of a branch of considerable size showing leaf bases and traces of the leaves. It is of somewhat doubtful validity in this connection.

Occurrence: Fruitland formation, 17 miles south of San Juan River and 2 miles east of Rio Chaco, San Juan County, N. Mex. Lot 26 (6949).

Family PONTEDERIACEÆ.

Heteranthera cretacea Knowlton, n. sp.

Plate LXXXV, figure 5.

Leaf evidently thick in texture, elliptical or very slightly ovate-elliptical, abruptly narrowed or rounded to a very narrow, short basal portion, rounded and slightly pointed at apex; three nerves arise in the basal portion of the blade or petiole, one passing up the center of the blade and the other two dividing the space between the first and the margin; from these three arise several others of equal strength, there being altogether 10 or 12, close, parallel, and all curving around to and apparently entering the tip; no other nervation discernible.

This curious little leaf is absolutely perfect except a minute portion of the tip. It is about 22 millimeters long including the narrow basal portion or petiole, which is 3 millimeters in length and 15 millimeters wide. It is almost elliptical, though it is perhaps 1 millimeter broader in the lower portion than in the upper. There are 11 or 12 nerves, only three of which arise in the basal portion, the others arising from them and all running into the tip.

The genus Heteranthera is a small one, comprising about nine species, two of which occur in tropical Africa and the others in America. Only three species are found in the United States. They are herbs growing in mud or shallow water, with creeping, ascending, or floating stems and petioled leaves which may be cordate, ovate, oval, reniform, or even grasslike. Of the three United States species the one most similar to the present form is *Heteranthera limosa* (Swartz) Willdenow, the smaller mud plantain, which ranges from Virginia to Kentucky and Missouri, south to Florida and Louisiana, and thence throughout tropical America. The living species bears numerous oval or ovate leaves 1.5 to 2.5 centimeters long on petioles 5 to 12 centimeters long. The several nerves all arise from or near the top of the petiole and arch around to the tip.

It will be noted that the fossil form agrees closely with this living species, the leaf being more nearly elliptical or ovate-elliptical and more abruptly pointed at the apex. The nerves as they pass from base to apex are very similar in both forms, but in the fossil leaf they do not all arise from the top of the petiole, as apparently they do in the living species. It is believed that the generic reference can hardly be questioned.

This species undoubtedly resembles and indeed may be identical with a little leaf from Point of Rocks, Wyo., which was referred by Lesquereux [1] to *Lemna scutata* Dawson and which I afterward,[2] probably incorrectly, regarded as merely a small leaf of *Pistia corrugata* Lesquereux. The leaf from Point of Rocks is much smaller than the leaf here described and is more nearly circular, but the "petiole" and the disposition of the nerves is much the same in both. It is certainly clear that the present leaf, as well as the one from Point of Rocks, is not the same as the type specimens of Dawson's *Lemna scutata*, and it is also reasonably certain that the present leaf can not belong to the genus Lemna.

Occurrence: Fruitland formation, Coal Creek, 35 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 81 (6955).

[1] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 102, pl. 61, fig. 5 [not fig. 3], 1878.

[2] Knowlton, F. H., U. S. Geol. Survey Bull. 163, p. 31, 1900.

Family ARACEÆ.

Pistia corrugata Lesquereux.

Plate LXXXV, figure 4.

Pistia corrugata Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 299 [1876]; U. S. Geol. Survey Terr. Rept., vol. 7, p. 103, pl. 61, figs. 1, 3, 4, 6, 7, 9–11, 1878.

Knowlton, U. S. Geol. Survey Bull. 163, p. 31, 1900.

One of the collections from the San Juan Basin contains a single example with its counterpart that undoubtedly belongs to *Pistia corrugata* as described by Lesquereux from specimens collected in the Montana group at Point of Rocks, Wyo. As may be seen from the figure, it is considerably broken and adds little or nothing to our knowledge of the species. It is about the same as the specimen shown in figure 7 of Lesquereux's plate in volume 7 of the Hayden Survey reports, in that it appears to be attached to the side of the thick stem, though it is perhaps really terminal and has been distorted in position during entombment. There appears to be a mass of rootlets by the side of the base, but these are so matted and compressed that their character can not be made out. The nervation is the same as that figured by Lesquereux, namely, an indeterminate number of veins arising in the base of the blade and spreading out and variously anastomosing above, producing very irregular polygonal meshes.

Pistia corrugata is said to be very abundant at Point of Rocks, Wyo., Lesquereux describing it as "covering by itself only large surfaces of shale." It was also found in beds of similar age at Superior, Wyo., by Schultz in 1907, in beds believed to be of Mesaverde age in the

Wind River Basin by Woodruff in 1909, and in the Judith River formation along Milk River, Mont., by Pepperberg in the same year. The questionable reference to this species of the specimens collected in 1908 near Alesua Mountain, N. Mex., by Gardner is now rendered more probably correct by the evidence of the present specimen.

The genus Pistia has had a very interesting geologic history. It is represented in the living flora by a single variable and widely distributed species (*Pistia stratioles* Linné). It is mainly tropical, ranging in this country from Florida to Texas and thence through the West Indies, Mexico, and Central America to Paraguay and Argentina. In Africa it ranges from Natal to Senegambia and Nubia, and thence to Madagascar and the Mascarene Islands. In Asia it is found throughout the East Indies and thence to the Philippines.

Of the four or five fossil species recognized, three are found in North America. The oldest of these is *Pistia nordenskiöldi* (Heer) Berry,[1] which occurs in the Magothy formation of Maryland and very abundantly in the Black Creek formation (Turonian) of North Carolina. It was first described by Heer[2] under the name *Chondrophyllum nordenskiöldi*, from specimens found in the Atane beds of Greenland.

The next species in point of age is *Pistia corrugata* Lesquereux, which has already been discussed.

The youngest American fossil form is *Pistia claibornensis*, from the Claiborne group (middle Eocene) of Georgia, recently described by Berry.[3] This differs markedly from the other forms by its obovate shape and strongly retuse apex.

The only accepted European fossil species is *Pistia mazeli* Saporta and Marion,[4] which occurs in the lignites of Furvean (Provence), France, and is of approximately the same age as *Pistia corrugata*. *Pistia mazeli* appears to be most closely related to the living form; in fact in the figures of the two species given side by side by Saporta and Marion it is almost impossible to note marks of distinction. In some ways it appears that the Claiborne species (*Pistia claibornensis*) is most closely related to *Pistia mazeli*, except that it is more retuse at the apex. However, its full character has not yet been made out, as it still depends on a single example in which little of the nervation has been retained.

The other two species (*Pistia corrugata* and *Pistia nordenskiöldi*) are themselves closely related and are also close to the living species, the main difference being their larger size and more anastomosing nerves.

The significant point brought out by this discussion is the fact that this peculiar plant, now so widely distributed over both hemispheres, was established in essentially its present form in late Cretaceous time, and even then occurred in both hemispheres. It is rather remarkable that so little has been ascertained regarding its Cenozoic history, in view of the great number of localities that have been investigated, yet the evidence that it must have persisted with very little change is brought out by the above exposition.

Occurrence: Kirtland shale, 1¼ miles northeast of Pina Veta China, San Juan County, N. Mex. Lot 96 (6965).

Family PALMACEÆ.

Sabal montana? Knowlton.

Plate LXXXV, figure 2.

Sabal montana Knowlton, U. S. Geol. Survey Prof. Paper 101, p. —, pl. 32, fig. 3 (in press).

Sabalites grayanus (Lesquereux) Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7, p. 112, pl. 12, fig. 1 [not pl. 12, fig. 2], 1878.

Most fossil palms are very difficult to identify and as a consequence are more or less unsatisfactory as stratigraphic criteria. The leaves are commonly of very large size and it is difficult to procure specimens that are anywhere near perfect, essential characters being in many specimens lacking or obscure. A specimen perhaps no larger than one's hand from a leaf that was possibly 5 or 6 feet in diameter can not fail to convey a very inadequate idea of its character, particularly the range in individual variation, and it is not at all improbable that too many species have been established.

The specimen under consideration is a case in point. It is a fragment, only about 10 centi-

[1] Berry, E. W., Torrey Bot. Club Bull., vol. 37, p. 189, pl. 21, figs. 1–15, 1910.

[2] Heer, Oswald, Flora fossilis arctica, vol. 3, p. 114, pl. 30, fig. 4b; pl. 32, figs. 11, 12, 1874.

[3] Berry, E. W., U. S. Geol. Survey Prof. Paper 84, p. 137, pl. 26, figs. 1–2, 1914.

[4] Saporta Gaston, and Marion, A. F., L'évolution du règne végétale, Phanérogames, vol. 2, p. 37, figs. 114c, 114d, 1885.

meters long, from some portion of the blade showing the petiole, or its prolongation, and the attachment of numerous rays. It appears to be from the under side of the leaf, but it is impossible to determine the length of this prolongation of the petiole or to estimate the number of rays with any degree of accuracy. It seems to belong to what has been named *Sabal montana*, as based on a considerable number of examples rather widely scattered through the several Montana localities, but on the other hand it is hardly to be distinguished from *Geonomites ungeri* Lesquereux,[1] a species supposed to be confined to the Raton and allied Eocene formations. *Geonomites ungeri* was established on a mere fragment from the middle of a leaf that was obviously of considerable size, and there is no means of knowing the size and configuration of the petiole, the number of rays, etc., and consequently there is no way to compare it with leaves referred to *Sabal montana*, in which these features are known. However, until more definite information is available the San Juan specimen may stand as *Sabal montana?*.

Occurrence: Fruitland formation, 18 miles south of San Juan River and 4 miles east of Chaco River, San Juan County, N. Mex. Lot 28 (6961).

Sabal? sp.

Plate LXXXV, figure 1.

The specimen here figured is the only one of its kind observed in the collections. It is a mere fragment from what apparently was a very large leaf, but it lacks so many essential features that it has seemed unwise to give it a specific name. When compared with the specimen figured as *Sabal montana?* it is seen to be very different, the prolongation of the rachis being especially strong and the rays very large at the point of their attachment. But the size of the leaf, the length of the rachis, and the number and configuration of the rays are unknown, and this fragment simply serves to call attention to the presence in these beds of a large palm.

Occurrence: Fruitland formation, just across San Juan River from Fruitland, about half a mile above the bridge, San Juan County, N. Mex. Lot 3 (6957).

[1] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 118, pl. 11, fig. 2, 1878.

Family **MYRICACEÆ**.

Myrica torreyi Lesquereux.

Plate LXXXVI, figure 1.

Myrica torreyi Lesquereux, U. S. Geol. and Geog. Survey Terr. Sixth Ann. Rept., for 1872, p. 392 [1873]; U. S. Geol. Survey Terr. Rept., vol. 7, p. 129, pl. 16, figs. 3-10, 1878.
Ward, U. S. Geol. Survey Sixth Ann. Rept., p. 551, pl. 40, fig. 4, 1886; Bull. 37, p. 32, pl. 14, fig. 5, 1887.
Knowlton, U. S. Geol. Survey Bull. 163, p. 34, pl. 6, figs. 1-3, 1900.
Cockerell, Colorado Univ. Studies, vol. 7, p. 150, 1910.

Only a few fragments of this species were found, but it is so well marked that these are sufficient to attest its presence in these beds.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 (6956).

Myrica? neomexicana Knowlton, n. sp.

Plate LXXXVI, figures 2-4.

Leaves small, deltoid in general outline, apparently truncate at the base and obtusely pointed at the apex; with at least 9 and probably as many as 11 or 13 lobes, the basal pair cut deeply or nearly to the midrib, becoming almost separate, others only slightly cut and in upper portion probably reduced to merely strong undulations; lobes obtuse, entire or more commonly strongly and obtusely toothed; nervation pinnate, the midrib being relatively strong; secondaries as many as the lobes, at a low angle of emergence, craspedodrome, ending in the lobes; finer nervation abundant and very irregular.

Although there are several specimens that obviously belong together they are so fragmentary that the species is very inadequately represented. It is roughly triangular or deltoid, and was at least 4 centimeters in length and very probably was considerably longer. The width at base was certainly over 4 centimeters, and if there was an additional free or nearly free lobe, its width must have been 6 centimeters or more.

Three specimens have been figured. In that shown in figure 3 the lobes are nearly or quite entire, but in the somewhat larger leaf shown in figure 2 the lobes are irregularly and obtusely toothed. The specimen shown in figure 4 is evidently the basal lobe of the leaf, but whether it belonged to a larger leaf or is another nearly detached lobe below the one shown in figure 2 is of course quite impossible to determine. Except for its close resemblance to the lower lobe like that in figure 2, this specimen might be considered an individual leaf, but it is broken on the upper side near the base, where it was undoubtedly connected to the other part of the blade.

Owing to the fragmentary nature of these specimens this generic reference is more or less uncertain. In some respects they are of the character of certain species of Myrica, such, for instance, as *Myrica alkalina* Lesquereux,[1] from the Green River formation of Wyoming, but they differ markedly in many essential particulars.

Occurrence: Kirtland shale, 3 inches below base of Ojo Alamo sandstone, 1½ miles northeast of Pina Veta China, San Juan County, N. Mex. Lot 40 (6966).

Family SALICACEÆ.

Salix baueri Knowlton, n. sp.

Plate LXXXVI, figures 7, 8.

Leaves small, of firm texture, narrowly elliptical-lanceolate, about equally narrowed to both base and apex; margin entire; midrib relatively very thick; other nervation obscure or wanting.

This little species is represented in the collections by some half dozen specimens, three of which are here figured. They are small leaves 3 or 4 centimeters in length and about 14 millimeters in greatest width. They are preserved on a very coarse grained matrix which has obscured or obliterated nearly all traces of nervation except the very thick midrib. An occasional secondary appears to be at an angle of about 45° and much curved upward near the margin.

These little leaves are so obscurely preserved that their full character can not be made out, and they are consequently of comparatively little stratigraphic value. They are of about the same size and shape as specimens of *Salix integra* Göppert from Black Buttes, Wyo., as figured by Lesquereux,[2] but the absence of most of the nervation makes it impossible to compare them satisfactorily with this species.

Occurrence: Fruitland formation, 10 miles south of San Juan River and 4 miles east of Chaco River, San Juan County, N. Mex. Lot 16 (6958).

[1] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8, p. 149, pl. 45A, figs. 10-15, 1883.

[2] Idem, vol. 7, p. 167, pl. 21, figs. 1, 2, 1878.

Salix sp. *a* Knowlton.

Plate LXXXVI, figure 9.

Salix sp. *a* Knowlton, U. S. Geol. Survey Prof. Paper 101, p. —, pl. 38, fig. 1 (in press).

The collection contains a number of willow leaves that are indistinguishable from a form described and figured from the Vermejo formation of the Raton Mesa region. The leaf figured here, which is one of the best, is about 8 centimeters in length and 1.8 centimeters in width. It has a very thick midrib and only faint indications of secondaries, which appear to be close, parallel, and at an angle of about 45°. It is so indistinctly preserved that it has not been thought desirable to give it a specific name.

Occurrence: Fruitland formation, 10 miles south of San Juan River and 4 miles east of Chaco River, San Juan County, N. Mex. Lot 16 (6958).

Family FAGACEÆ.

Quercus baueri Knowlton, n. sp.

Plate LXXXVI, figures 5, 6.

Leaf small, of coriaceous texture, ovate-elliptical, about equally rounded to both base and apex; margin provided with relatively strong, rather obtuse teeth; midrib very strong; secondaries about four pairs, strong, alternate, craspedodrome, terminating in the teeth; finer nervation obscure.

The specimen here figured is nearly perfect and is 3.5 centimeters long and 2 centimeters wide. It was evidently a rather thick and coriaceous leaf, as is attested both by its thick nervation and by its general appearance.

This species has some resemblance to an unpublished species of Quercus from the Vermejo formation but differs in its slightly smaller size and less prominent teeth.

Occurrence: Fruitland formation, from clinker above highest coal bed, 30 miles south of Farmington and 1 mile east of reservation line, San Juan Basin, N. Mex. Lot 75 (6956).

Family MORACEÆ.

Ficus baueri Knowlton, n. sp.

Plate LXXXIX, figure 2.

Leaves of medium size and firm texture, ovate, rather abruptly rounded to the apparently truncate base, acuminate at apex; midrib strong, straight; secondaries three or four pairs, very remote, alternate, at an angle of 45°, strong below, much thinner and almost disappearing above, probably camptodrome; nervilles thin, very obscure, oblique to the midrib; finer nervation not retained.

The specimen figured, although it lacks a considerable portion of the leaf, is sufficient to give a good idea of this species. It is very regularly ovate, about 115 centimeters in length and 7 centimeters in greatest width, which is above the middle of the blade. It is remarkable for its strong midrib and its few, remote, alternate secondaries.

This species is in a way of the type of *Ficus denveriana* Cockerell,[1] a well-known Denver species. It differs markedly in nervation, however, as it has only three or four pairs of very remote secondaries, while the Denver form has not less than ten or twelve pairs of relatively close parallel secondaries. The manner in which the secondaries reach the margin is also very different in the two forms, and hence they can not be considered as at all closely related.

Occurrence: Fruitland formation, in clinker above highest coal bed, 30 miles south of Farmington and 1 mile east of reservation line, San Juan Basin, N. Mex. Lot 75 (6956).

Ficus curta? Knowlton.

Plate LXXXVIII, figure 3.

Ficus curta Knowlton, U. S. Geol. Survey Prof. Paper 101, p. —, pl. 42, fig. 5 (in press).

The type of this species comes from the Vermejo formation of the Canon City coal field, Colorado, and is described and figured in the report cited.

The specimen here figured lacks most of the margin, but so far as can be made out it appears to agree with the leaf from Colorado.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 (6956).

[1] A new name for *Ficus spectabilis* Lesquereux, which proved to be preoccupied. See U. S. Geol. Survey Terr. Rept., vol. 7, pl. 33, figs. 4-6, 1878.

Ficus prætrinervis Knowlton.

Ficus prætrinervis Knowlton, U. S. Geol. Survey Prof. Paper 101, p. —, pl. 41, figs. 1-4; pl. 42, fig. 1 (in press).

The types of this species come from the Vermejo formation of the Raton Mesa region of Colorado and New Mexico and are described and figured in the report cited. It is a well-marked and exceedingly abundant form in the Vermejo formation and appears to be also abundant and well defined in the San Juan Basin.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lots 75 (6956) and 78 (6952).

Ficus leei Knowlton.

Plate XC, figure 2.

Ficus leei Knowlton, U. S. Geol. Survey Prof. Paper 101, p. —, pl. 39, figs. 1-6; pl. 40, figs. 1, 2 (in press).

The types of this fine species come from the Vermejo formation of the Raton Mesa region of Colorado and New Mexico and are described and figured in the report cited. It is one of the most abundant and well-marked forms of the Vermejo formation.

Ficus leei is also fairly abundant in the San Juan Basin, though the leaves are somewhat smaller than the average size of those from the type area, but they do not otherwise differ.

Occurrence: Fruitland formation, Amarillo Canyon, 10 miles south of San Juan River and 4 miles east of Chaco River, N. Mex., lot 16 (6958); 30 miles south of San Juan River and 4½ miles east of reservation line, San Juan County, N. Mex., lot 74 (6963). Kirtland shale; 1½ miles northeast of Pina Veta China, San Juan County, N. Mex., lot 40 (6966).

Ficus prælatifolia Knowlton, n. sp.

Plate LXXXVII, figure 4.

Leaves large, broadly ovate, truncate or slightly heart-shaped at base, probably obtuse above; nervation strongly three-ribbed from the top of the petiole, the midrib stronger, with several pairs of subopposite secondaries high up above the base; lateral ribs with six or seven secondary camptodrome branches on the outside; nervilles numerous, strong, mostly unbroken.

This species is represented by a number of examples, one of the best of which is figured. It was probably not less than 13 or 14 centimeters in length and about 9 centimeters in width, but the exact length can only be inferred. It was conspicuously longer than broad. The strong, three-ribbed nervation and other details are well shown in the figure.

This form appears to be most closely related to *Ficus planicostata latifolia* Lesquereux [1] (later called *Ficus latifolia* (Lesquereux) Knowlton), which was described originally from specimens collected at Black Buttes, Wyo., but has since been discovered at a number of other localities. If only the basal portion was present it would be extremely difficult to distinguish the San Juan leaf from the previously named species, but the shape of the whole leaf is very different. Thus, in *Ficus planicostata latifolia* the blade is very much broader than long, but in the one under consideration the reverse is true.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 (6956).

Ficus sp.

Plate LXXXIX, figure 1.

The single much-broken specimen figured is the only one noted. It is a rather large leaf (about 12 centimeters long and 6.5 centimeters wide) elliptical-ovate, with apparently a slightly heart-shaped base, and entire margin. The entire upper part is missing. The nervation consists of a rather slender midrib and an unknown number of thin, remote, alternate secondaries, the lower of which has several tertiary branches on the lower side. None of the finer nervation is retained, owing to the coarse-grained matrix.

This form is so poorly preserved that it is hardly worth while to institute comparisons between it and various named species.

Occurrence: Fruitland formation, Amarillo Canyon, 10 miles south of San Juan River and 4 miles east of Chaco River, San Juan County, N. Mex. Lot 16 (6958).

[1] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 202, pl. 31, fig. 9, 1878.

Ficus rhamnoides Knowlton.

Plate LXXXVII, figure 3.

Ficus rhamnoides Knowlton, U. S. Geol. Survey Bull. 163, p. 47, pl. 10, figs. 1-3; pl. 11, fig. 1, 1900.

This species was described originally from specimens found in the Montana group at Point of Rocks, Wyo. The specimen figured here, although lacking all the lower half of the leaf, agrees in every particular with the original specimens.

Occurrence: Fruitland formation, 13 miles south of San Juan River and 1 mile east of Chaco River, San Juan County, N. Mex. Lot 23 (6960).

Ficus squarrosa? Knowlton.

Plate LXXXVI, figure 10.

Ficus squarrosa Knowlton, U. S. Geol. Survey Bull. 163, p. 45, pl. 8, fig. 2, 1900.

The single example figured is referred with doubt to this species. It is a much smaller leaf than the type but does not appear to differ essentially otherwise. It is so poorly preserved, however, that it seems best to question the full identification.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 76 (6963).

Ficus sp.

Plate LXXXVIII, figure 1.

Leaf large, apparently nearly circular in general outline, rather broadly heart-shaped at base, probably rounded above; nervation strongly marked, consisting of seven ribs from the top of the petiole, the central or midrib slightly the stronger, with two pairs of opposite, remote secondaries, other ribs (three on each side) about equally dividing the broad blade into four areas, the inner pair of ribs joining the lower secondaries of the midrib; the lower ribs with tertiary branches on the outside which join by a series of broad loops just inside the margin; nervilles numerous, very strong, mainly broken; finer nervation producing quadrangular areolæ.

This form is undoubtedly very well marked, but unfortunately it lacks nearly all the margin except at the base and for a distance of some 4 centimeters above it. This leaf was probably 11 or 12 centimeters long and hardly less than

12 centimeters broad. The rather deeply heart-shaped base, seven strong ribs, strongly looping tertiaries, and strong, broken nervilles would make it easy of recognition though it lacks so much of the blade.

This leaf suggests at once *Ficus wardii* Knowlton,[1] from the Montana group at Point of Rocks, Wyo. That species, however, is smaller and has a shallower heart-shaped base and only five instead of seven ribs. The lower or outer ribs in *Ficus wardii* have numerous regular, parallel tertiary branches quite unlike the tertiaries in the present form. These characters should make it easy of recognition in the future.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 (6956).

Ficus eucalyptifolia? Knowlton.

Plate LXXXVII, figures 1, 2.

Ficus eucalyptifolia Knowlton, U. S. Geol. Survey Prof. Paper 101, p. —, pl. 44, figs. 1, 2 (in press).

The types of this species come from the Vermejo formation of Rockvale, Colo., and are described and figured in the report cited. The San Juan Basin material embraces a number of leaves that appear to belong to this species, but as they are rather poorly preserved it has seemed best to question the reference. They are, so far as can be made out, of the same size and shape as the types, but the nervation, with the exception of the strong midrib, is obscure. The secondaries appear to be very thin, evenly spaced, and parallel, but their termination near the margin can not be seen.

Occurrence: Fruitland formation, 13 miles south of San Juan River and 1 mile east of Chaco River, San Juan County, N. Mex. Lot 23 (6960).

Family LAURACEÆ.

Laurus baueri Knowlton, n. sp.

Plate LXXXIX, figure 5.

Leaf evidently of thick texture and probably evergreen, lanceolate, narrowed in about equal degree to the wedge-shaped base and apparently acuminate apex (actual base and apex not preserved); margin entire, provided with a thick "cord" which makes the actual margin; midrib relatively thick, straight; secondaries very thin, alternate, at an angle of 30° or 40°, much curved upward and disappearing just inside the margin or each joining by a series of very thin loops to the one next above; nervilles all very much broken and irregular and forming different-sized areolæ.

The example figured is the only one observed. It is a narrowly lanceolate, slightly unequal-sided leaf about 9 centimeters long and a little over 2.5 centimeters wide. It is remarkable in that the margin is formed by a thick fibrous "cord" nearly 1 millimeter in width, which otherwise resembles a secondary branch. The midrib is very thick for the size of the leaf, but the secondaries are thin and delicate. The actual leaf substance is retained as a thin membranaceous carbonaceous film, which shows all the details of the nervation as completely as could be seen in a living leaf. When this carbonaceous film is removed it is found that the details of nervation are very faintly impressed on the matrix. It seems probable, from the thick midrib, the woody marginal "cord," and the faintly impressed secondaries, that the leaf was originally thick and coriaceous and not unlikely was evergreen.

This species is of the general type of certain of the leaves referred by Lesquereux[2] to *Laurus socialis*, a well-known Tertiary form. It differs from that species, however, in its larger size, fewer secondaries, which curve upward for a longer distance, and above all in the presence of the marginal "cord."

Occurrence: Fruitland formation, 2 miles east of Chaco River, San Juan Basin, N. Mex. Lot 14 (6948).

Laurus coloradensis Knowlton.

Plate LXXXVIII, figures 4, 5.

Laurus coloradensis Knowlton, U. S. Geol. Survey Prof. Paper 101, p. —, pl. 45, fig. 3 (in press).

The type of this species comes from the Vermejo formation at Rockvale, Colo., and is described and figured in the report cited. The two leaves here figured are somewhat smaller than the type but do not appear to differ essentially in any other particular.

Occurrence: Fruitland formation, 13 miles south of San Juan River and 1 mile east of Chaco River, San Juan County, N. Mex. Lot 23 (6960).

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[1] Knowlton, F. H., Flora of the Montana formation: U. S. Geol. Survey Bull. 163, p. 48, pl. 9, fig. 1, 1900.

[2] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 213, pl. 36, figs. 1-4, 7, 1878.

Family NYMPHÆACEÆ.

Nelumbo sp.

Plate LXXXVI, figure 11.

The San Juan Basin collections include the specimen here figured, which appears to belong to Nelumbo. It is a fragment from near the central part of what was a perfoliate leaf of considerable size, though none of the margin is now retained. The leaf was at least 12 centimeters in diameter and very likely was nearly twice this size. It was evidently very thick, as is proved by the fact that the ribs seem deeply embedded in the leaf substance—so deeply, in fact, that it is impossible to determine their exact number, though there were apparently as many as 18 or 20. There is also evidence that some of them were unforked. None of the other details can now be made out.

It is hardly worth while to attempt comparisons between this and described species of the genus, as so many of its characters are obscure or missing. It appears, however, to be of the type of the common living *Nelumbo lutea* (Willdenow) Persoon, the water chinkapin of lakes and streams.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 76 (6953).

Family MIMOSACEÆ.

Leguminosites? neomexicana Knowlton, n. sp.

Plate XC, figures 3, 4.

Leaflet minute, about 11 millimeters in length and 5 millimeters in width, ovate-lanceolate, rounded and apparently truncate at base, acuminate at apex; midrib very thick for the size of the blade; secondaries extremely thin, about four pairs, alternate, camptodrome, each joining the one next above and forming a bow far inside the margin; finer nervation not retained.

It must be confessed that this leaflet is of little stratigraphic value, its main interest being in the evidence it affords of the presence of vegetation of this type in these beds. It is so very small and on the whole so poorly preserved that comparisons with other forms referred to this type will not be attempted.

Occurrence: Kirtland shale, 1½ miles northeast of Pina Veta China, San Juan County, N. Mex. Lot 40 (6966).

Family STERCULEACEÆ.

Pterospermites undulatus Knowlton.

Plate XC, figure 5.

Pterospermites undulatus Knowlton, U. S. Geol. Survey Bull. 163, p. 67, pl. 16, fig. 3; pl. 17, fig. 2; pl. 18, fig. 4, 1900.

The example figured, which unfortunately is much broken, appears to be referable to this species. It is of about the average size of those from Point of Rocks, Wyo., and with the exception of being a little more rounded below does not differ essentially.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 (6956).

Pterospermites neomexicanus Knowlton, n. sp.

Plate XC, figure 6.

Leaf evidently thin in texture, ovate, abruptly truncate and slightly heart-shaped at base, acuminate at apex; margin entire below, becoming slightly undulate in the middle and few-toothed in the upper third, the teeth small, sharp, pointing outward, and separated by very shallow sinuses; midrib slender; secondaries about four pairs, subopposite, remote, the lower pair arising near the top of the petiole, with five or six branches on the lower or outer side, the lowest with several tertiary camptodrome branches on the lower side; upper secondaries simple or occasionally branched; nervilles few, irregular; finer nervation not retained.

This leaf is regularly ovate, about 8 centimeters long and 5.5 centimeters wide at the broadest point, which is just below the middle. It is otherwise distinguished by its few secondaries and by the margin entire below and undulate and finely toothed above.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 (6956).

Pterospermites sp.

Plate LXXXIX, figure 3; Plate XC, figure 1.

One of the collections contains a fragment of a very large leaf that apparently belongs to the genus Pterospermites. It could hardly have been less than 18 centimeters in length and was at least 14 centimeters in width. It was apparently broadly ovate, rounded at the base, with the margin strongly undulate-toothed, both the teeth and the sinuses separating them being rounded. The secondaries are strong, occasionally forked, approximately parallel, and craspedodrome. Nervilles rather scattered, somewhat irregular but usually unbroken. Finer nervation producing an irregularly quadrangular mesh.

Associated in the same collection is the specimen shown in figure 1, which represents the basal portion of a large leaf that is probably the same species as that shown in Plate LXXXIX, figure 3. It is deeply heart-shaped at the base. The midrib is very strong, and the secondaries are at a very low angle. The petiole is preserved for a length of 1.5 centimeters and is very thick and strong.

This leaf, which is obviously too much broken to admit of satisfactory diagnosis, appears to be congeneric with *Pterospermites undulatus* Knowlton,[1] from Point of Rocks, Wyo., but it was much larger and has a more markedly undulate margin. The secondaries appear to emerge from the midrib at a lower angle than in the Point of Rocks form, but this point is obscure. The finer nervation is about the same in both forms.

Occurrence: Kirtland shale; 1½ miles northeast of Pina Veta China, San Juan County, N. Mex. Lot 40 (6966).

Family GROSSULARIACEÆ.

Ribes neomexicana Knowlton, n. sp.

Plate LXXXIX, figure 4.

Leaf small, firm in texture, broader than long, three-lobed, the lateral lobes strongly toothed (central lobe much broken); base truncate or very slightly heart-shaped; nervation not well retained, consisting at least of a fairly strong midrib and two lateral ribs that arise at or near the base and supply the lateral lobes, each apparently with several branches on the outside that end in the marginal teeth.

This little leaf, the only one of its kind in the collections, is broadly ovate in general outline, about 2 centimeters long and nearly 3 centimeters broad. It appears to be rather deeply three-lobed, and each of the lateral lobes is provided with five or six strong pointed teeth. The middle lobe is so much broken that its exact shape can not be made out, though it was doubtless toothed like the others.

Occurrence: Fruitland formation, 10 miles south of San Juan River and 4 miles east of Chaco River, San Juan County, N. Mex. Lot 16 (6958).

[1] Knowlton, F. H., U. S. Geol. Survey Bull. 163, p. 67, pl. 17, fig. 2, 1900.

INCERTÆ SEDES.

Carpites baueri Knowlton, n. sp.

Plate LXXXVIII, figure 2.

Fruit spheroidal, about 11 by 13 millimeters in short and long diameter, much compressed; surrounded by an exocarp fully 1 millimeter thick; "stone" deeply sulcate at one end but not otherwise marked.

The example figured is the only one found in the collections and consequently its exact character is difficult to determine; in fact, it is impossible to be certain of its orientation. The sulcation on one side is probably opposite the point of attachment. The nature of the outer covering is difficult to interpret. It could hardly have been fleshy, as it is so uniform in thickness and so distinct, and probably it was an exocarp similar to that in certain species of Carya. The inner portion, or "shell," is without markings except the deep furrow on one side. It is perhaps needless to add that its affinity is not known.

Occurrence: Fruitland formation, Coal Creek, 35 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 81 (6955).

Phyllites petiolatus Knowlton, n. sp.

Plate XCI, figure 3.

Leaves small, membranaceous in texture, elliptical-lanceolate, long wedge-shaped at base, apparently narrowly acuminate at apex; margin perfectly entire; petiole very strong, more than 2.5 centimeters in length; midrib very strong below, becoming thin in the upper third of the leaf; secondaries four pairs, alternate, at an angle of about 50°, each running up for a long distance and disappearing in or near the margin or joining the secondary next above; nervilles numerous, very thin, mainly unbroken, at right angles to the secondaries; finer nervation obscure.

The leaf figured is the best one observed. It is about 7 centimeters long and slightly over 2 centimeters in width, the petiole, as already stated, adding at least 2.5 centimeters to the total length. This species may be known by its elliptical-lanceolate shape, long wedge-shaped base, long, thick petiole, and only four pairs of alternate secondaries.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 (6956).

Phyllites neomexicanus Knowlton, n. sp.

Plate XCI, figure 2.

Leaf small, rather thick in texture, slightly obovate-elliptical, rather abruptly wedge-shaped at base, apparently rounded and rather obtuse above; margin entire; midrib relatively strong; secondaries about five pairs, subopposite, remote, at an angle of about 50°, somewhat turned upward, camptodrome or just barely reaching the margin; nervilles mainly unbroken, somewhat oblique to the secondaries.

This little leaf is 6.5 centimeters in length and 3 centimeters in width just above the middle.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 (6956).

Unassigned plant (a).

Plate XCI, figures 4-9.

In one of the collections there are several specimens of a plant whose exact affinity has not been ascertained. The most complete example, shown in figure 8 (enlarged in fig. 9), is pinnate, with several narrowly lanceolate fern-like "pinnæ," about 15 millimeters long and 5 millimeters broad, with two close rows of small, scythe-shaped organs (pinnules or leaflets). Some of the little "pinnules" (see fig. 4) are short-petioled; others are nearly or quite sessile below, becoming confluent above. In the upper portion of some of the "pinnæ" the "pinnules" are set so closely that the blades distinctly overlap.

The nervation of the "pinnules" is peculiar. A single vein arises from the petiole at the lower margin of the blade and forks just above its point of origin; the lower branch usually traverses the length of the blade and occasionally branches or forks, and the upper one distinctly forks once or twice into equal branches entirely after the manner of a fern.

The size and general appearance of this little plant, as well as the shape and close overlapping of many of the foliar organs ("pinnules" or "leaflets"), are somewhat suggestive of Selaginella, but if it were of that genus it should belong to a type in which there should be present two other rows of minute scalelike leaves, and nothing of the kind has been detected. Moreover, the nervation does not agree with the nervation of Selaginella.

On first inspection it suggested *Selaginella falcata* Lesquereux,[1] from Point of Rocks, Wyo., but closer study shows that the "leaves" are much broader in the present material and have a quite different nervation.

The pinnate arrangement of the narrow "pinnæ," the appearance of the "pinnules," and above all the forking nervation suggest a small delicate fern of the asplenoid type, but Mr. W. R. Maxon, to whom the specimen was shown, is quite certain it is not a pteridophyte.

Considering these uncertainties as to its affinities, I will not venture to place it biologically until more and better material is available.

Occurrence: Kirtland shale, 1½ miles northeast of Pina Veta China, San Juan County, N. Mex. Lot 43 (6965).

Unassigned plant (b).

Plate XCI, figure 1.

In one of the collections of red baked shale there is a specimen that is worthy of brief mention, although it is very fragmentary and hence difficult of allocation. It consists of a fragment of a stem about 4 centimeters in length and about 4 millimeters in diameter. It bears apparently opposite or subopposite leaves, whose sheathing bases cover the stem for a considerable distance below each node. The leaves are lanceolate and slightly constricted at the base and presumably acute at the apex, though no tips are preserved. The leaves are retained for a length of about 1.5 centimeters, but may well have been many times this length. They are unkeeled and pro-

[1] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 46, pl. 61, figs. 12-15, 1878.

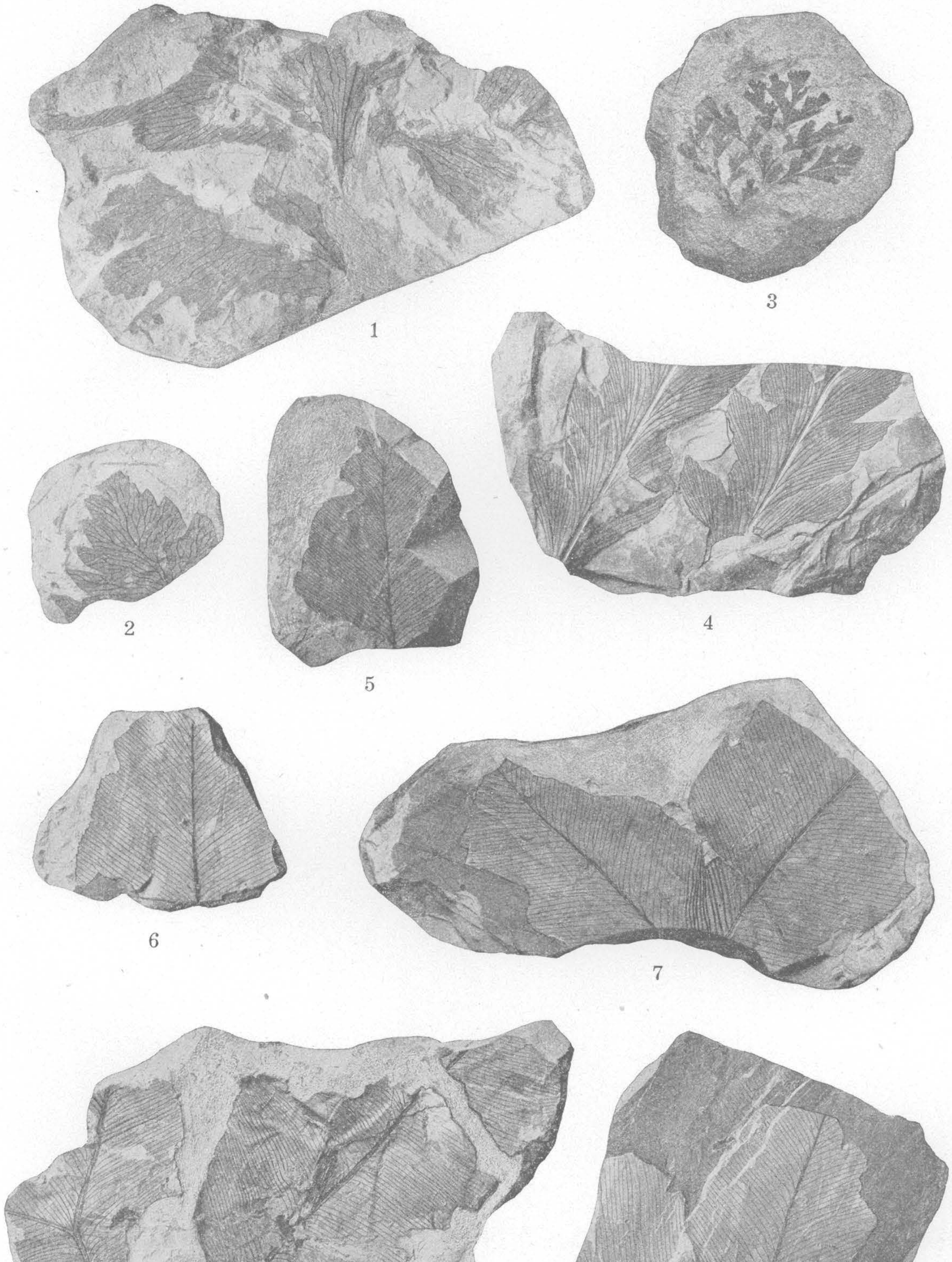
vided with numerous close, fine, parallel veins with cross veinlets.

The affinity of this plant has not been determined. The leaves with their sheathing bases suggest a sedge, but this is hardly more than a suggestion, for they do not agree with the combined characters of this group. The plant is evidently a monocotyledon and in general appearance somewhat resembles some of the leafy-stemmed forms of Cypripedium or Habenaria, but this resemblance is perhaps hardly more than superficial, and the fact remains that the specimen is too fragmentary to permit complete identification.

Occurrence: Fruitland formation, 30 miles south of Farmington and 1 mile east of reservation line, San Juan County, N. Mex. Lot 75 [6956].

PLATES LXXXIV-XCI.

PLATE LXXXIV.



FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.

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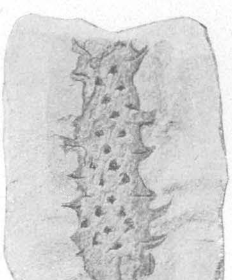


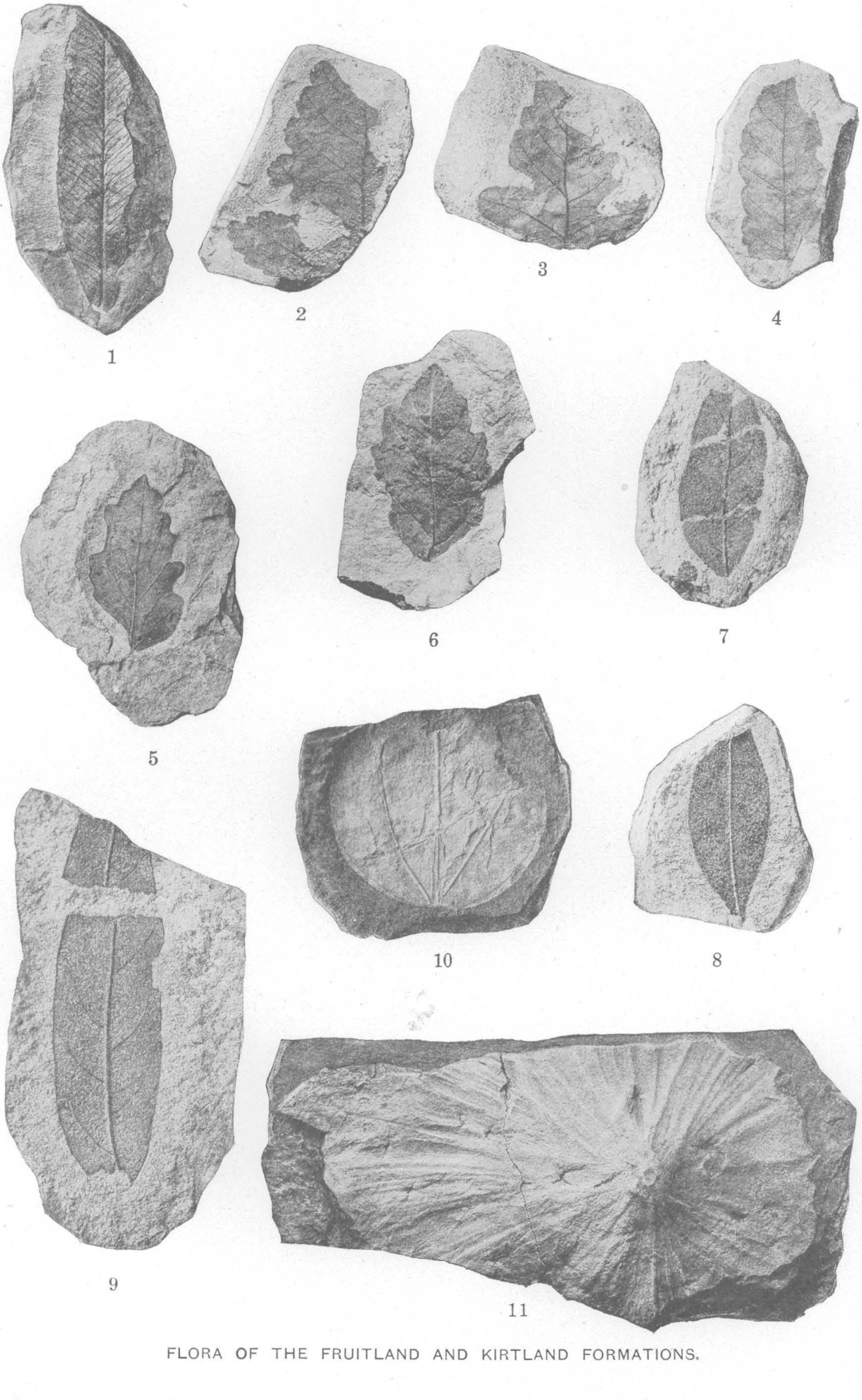
3

2

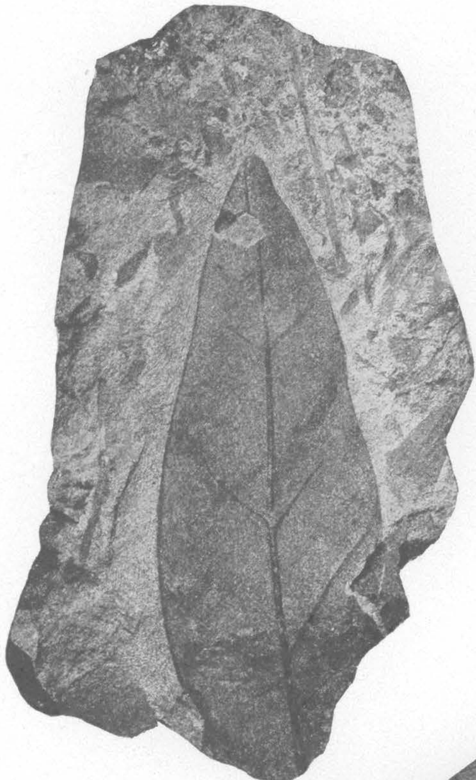
FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.

PLATE LXXXV.

PLATE LXXXVI.



FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.



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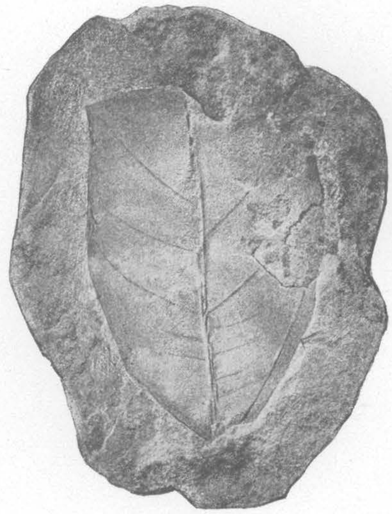

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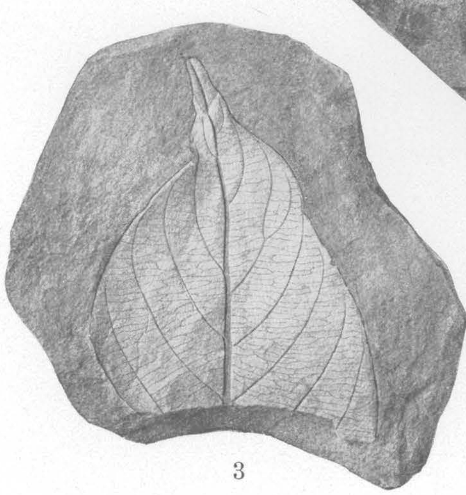
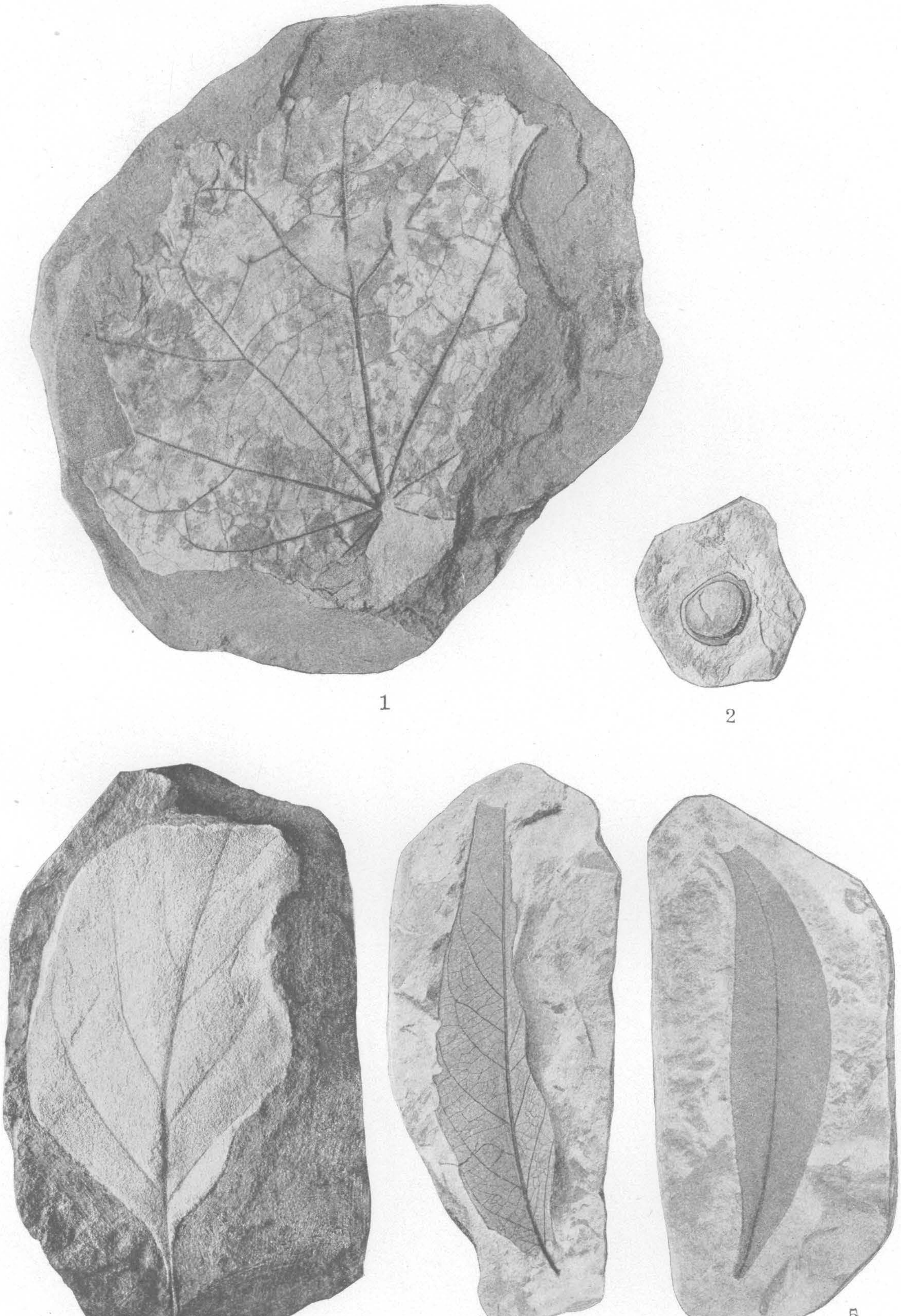


3

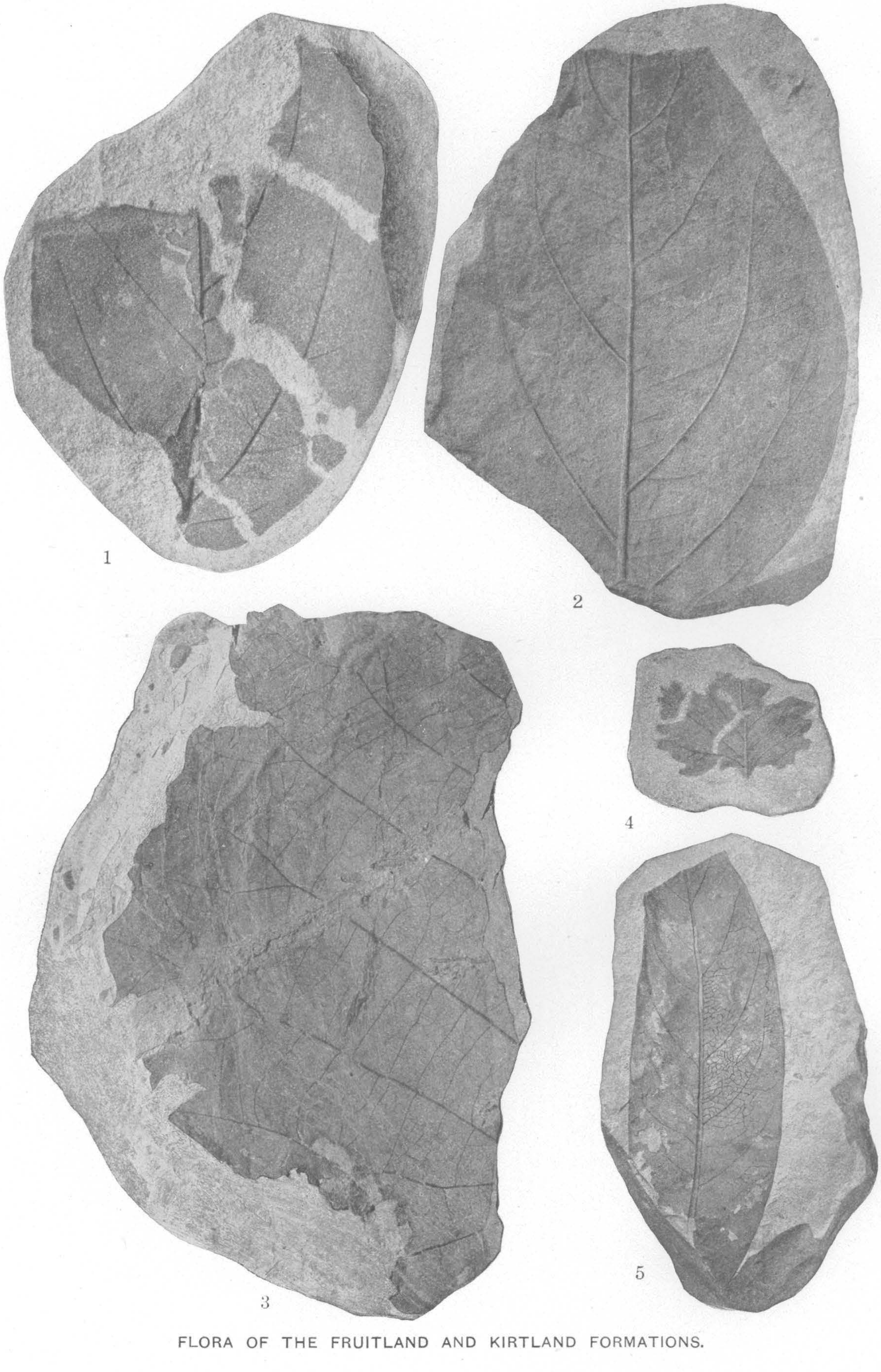
FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.

PLATE LXXXVII.

PLATE LXXXVIII.



FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.



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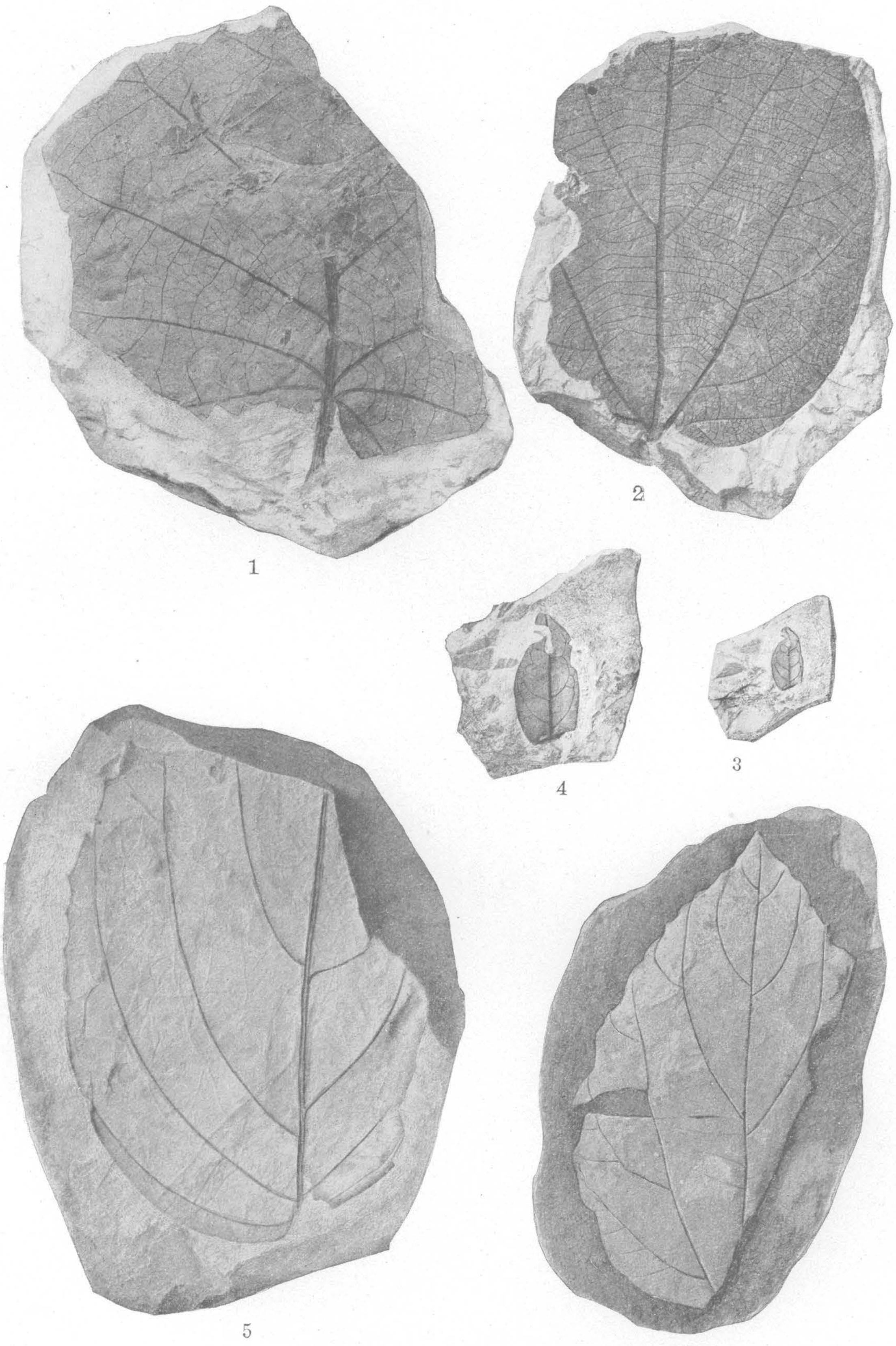
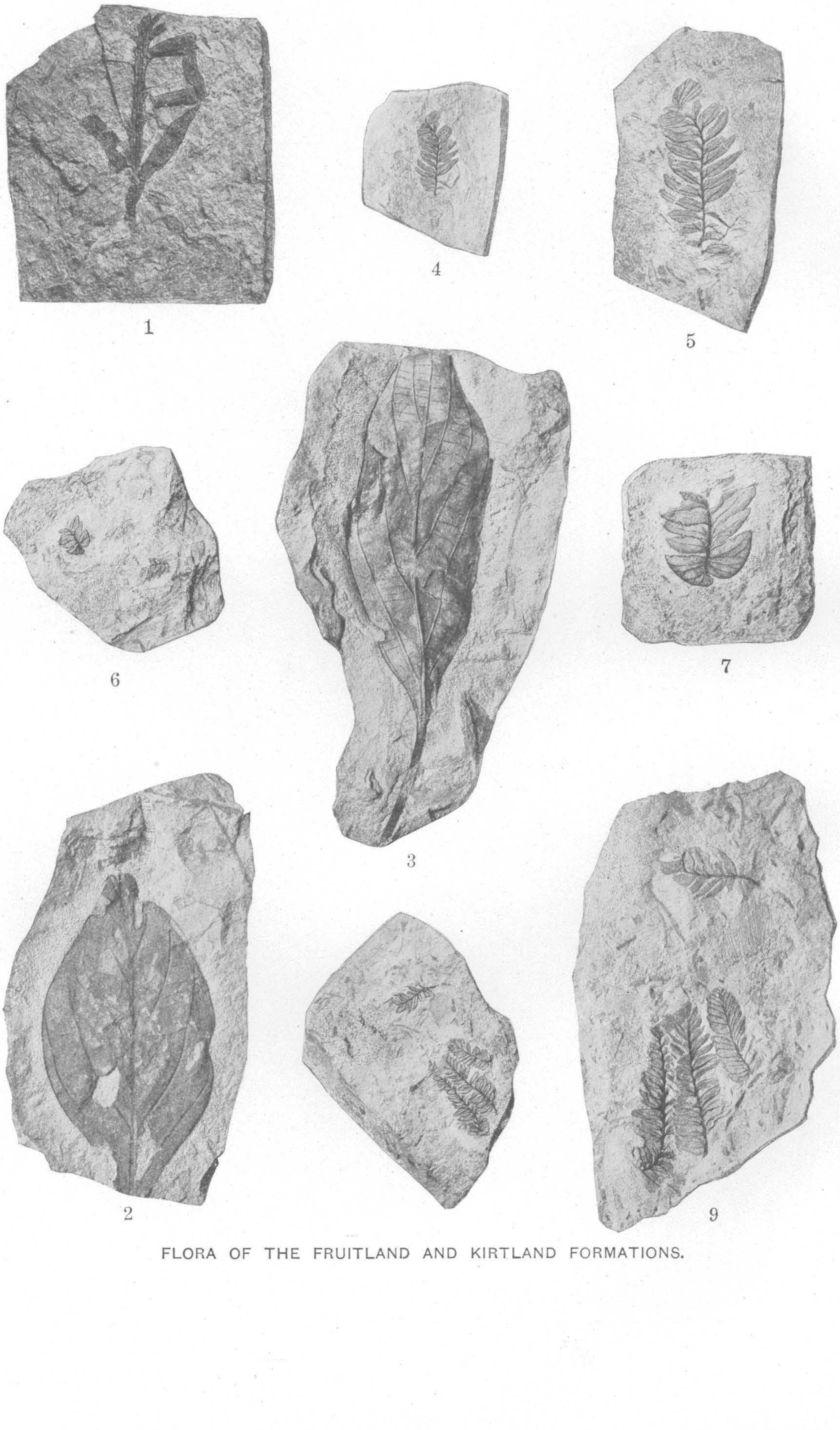
FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.

PLATE LXXXIX.

PLATE XC.



FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.



FLORA OF THE FRUITLAND AND KIRTLAND FORMATIONS.

PLATE XCI.

THE REEF-CORAL FAUNA OF CARRIZO CREEK, IMPERIAL COUNTY, CALIFORNIA, AND ITS SIGNIFICANCE.

By Thomas Wayland Vaughan.

INTRODUCTION.

Knowledge of the existence of the unusually interesting coral fauna here discussed dates from the exploration of Coyote Mountain (also known as Carrizo Mountain) by H. W. Fairbanks in the early nineties.[1] Dr. Fairbanks sent the specimens of corals he collected to Prof. John C. Merriam, at the University of California, who in turn sent them to me. There were in the collection representatives of two species and one variety, which I described under the names *Favia merriami*,[2] *Stephanocœnia fairbanksi*,[3] and *Stephanocœnia fairbanksi* var. *columnaris*.[4] As the geologic horizon was not even approximately known at that time, I gave it as "doubtfully Cretaceous" in the paper cited.

Late in 1903 Dr. Stephen Bowers sent to me for examination a small collection of fossils obtained by him in the Carrizo Creek area during June and July, 1901.[5] This collection contained corals whose affinities are undoubtedly with Pliocene, Pleistocene, and Recent species of the western Atlantic region, and not with any known living Indo-Pacific fauna. The following statement was made in a paper based on this collection.[6]

> In the collection that has so far been made from the California fossil reef five genera are represented, all of which occur in the fossil and recent faunas of the Antilles and not one of which is at present known to occur on the Pacific coast. The age of the beds in which these fossils occur has been determined by Drs. Arnold and Dall to be lower Miocene. The following conclusions seem warranted: (1) There was water connection between the Atlantic and Pacific across Central America not much previous to the upper Oligocene or lower Miocene—that is, during the upper Eocene or lower Oligocene. This conclusion is the same as that reached by Messrs. Hill and Dall, theirs, however, being based upon a study of the fossil mollusks. (2) During lower Miocene time the West Indian type of coral fauna extended westward into the Pacific, and it was subsequent to that time that the Pacific and Atlantic faunas have become so markedly differentiated.

As it will be made evident on subsequent pages that this fauna is much younger than lower Miocene, the inference as to the date of the interoceanic connection given in the foregoing quotation must be modified.

After receiving the specimens from Dr. Bowers and recognizing the need of more careful geologic studies in the Carrizo Creek area, I brought the matter to the attention of C. W. Hayes, then chief geologist of the Survey, and in January, 1904, arrangements were made for an expedition to the region, in charge of W. C. Mendenhall, who was accompanied by Dr. Bowers. Mr. Mendenhall conducted the physiographic and stratigraphic studies and Dr. Bowers made a large collection of fossils.

As it was my intention to publish promptly an account of the fossil corals, I furnished to Ralph Arnold, for publication in his paper entitled "The Tertiary and Quaternary pectens of California,"[7] a list which contained three nomina nuda, but other duties prevented my completing a report until the summer of 1916. The list furnished and published was based on the collection submitted by Dr. Bowers before he made the expedition with Mr. Mendenhall. It is given in the first column of the list on page 356. The second column gives the names applied in this paper.

[1] California State Min. Bur. Eleventh Ann. Rept., pp. 88-90, 1893.

[2] Vaughan, T. W., The Eocene and lower Oligocene coral faunas of the United States: U. S. Geol. Survey Mon. 39, p. 142, pl. 15, figs. 5, 5a, 5b, 5c, 1900.

[3] Idem, p. 151, pl. 17, figs. 11, 11a.

[4] Idem, pp. 151, 152, pl. 17, figs. 10, 10a.

[5] A brief report on his field observations was made by Dr. Bowers in an article entitled "Reconnaissance of the Colorado Desert mining district," 19 pp., California State Min. Bur., 1901.

[6] Vaughan, T. W., A Californian Tertiary coral reef and its bearing on American recent coral faunas: Science, new ser., vol. 19, p. 503, Mar. 24, 1904.

[7] U. S. Geol. Survey Prof. Paper 47, p. 22, 1906.

Fossil corals from Carrizo Creek, Cal.

Name in Prof. Paper 47, p. 22.	Revised name.
Diploria bowersi Vaughan (MS.).	Mæandra bowersi Vaughan.
Favia merriami Vaughan.	Dichocœnia merriami (Vaughan).
Plesiastrea californica Vaughan (MS.).	Solenastrea fairbanksi (Vaughan).
Siderastrea californica Vaughan (MS.).	Siderastrea californica Vaughan.
Stephanocœnia fairbanksi Vaughan.	Solenastrea fairbanksi (Vaughan).
Stephanocœnia fairbanksi var. columnaris Vaughan.	Solenastrea fairbanksi var. columnaris (Vaughan).

Messrs. Mendenhall and Bowers shipped to Washington over 400 specimens of corals, and it is on this large collection that the present paper is mostly based. All the photographs of corals herein illustrated were made by Mr. W. O. Hazard, except those for Plate XCIX, which were contributed by Dr. Charles Gravier, of Paris. Miss Frances Wieser has retouched some of the photographs. The illustrations showing the geologic conditions under which the fossil corals occur are reproductions of photographs taken by Mr. Mendenhall, and I am making extensive quotations from his article entitled "Notes on the geology of Carrizo Mountain and vicinity, San Diego County, Cal." [1]

GEOGRAPHIC RELATIONS.

The accompanying sketch map (fig. 43) is taken from the article by Mr. Mendenhall, who gives the following graphic description of the general geographic relations:

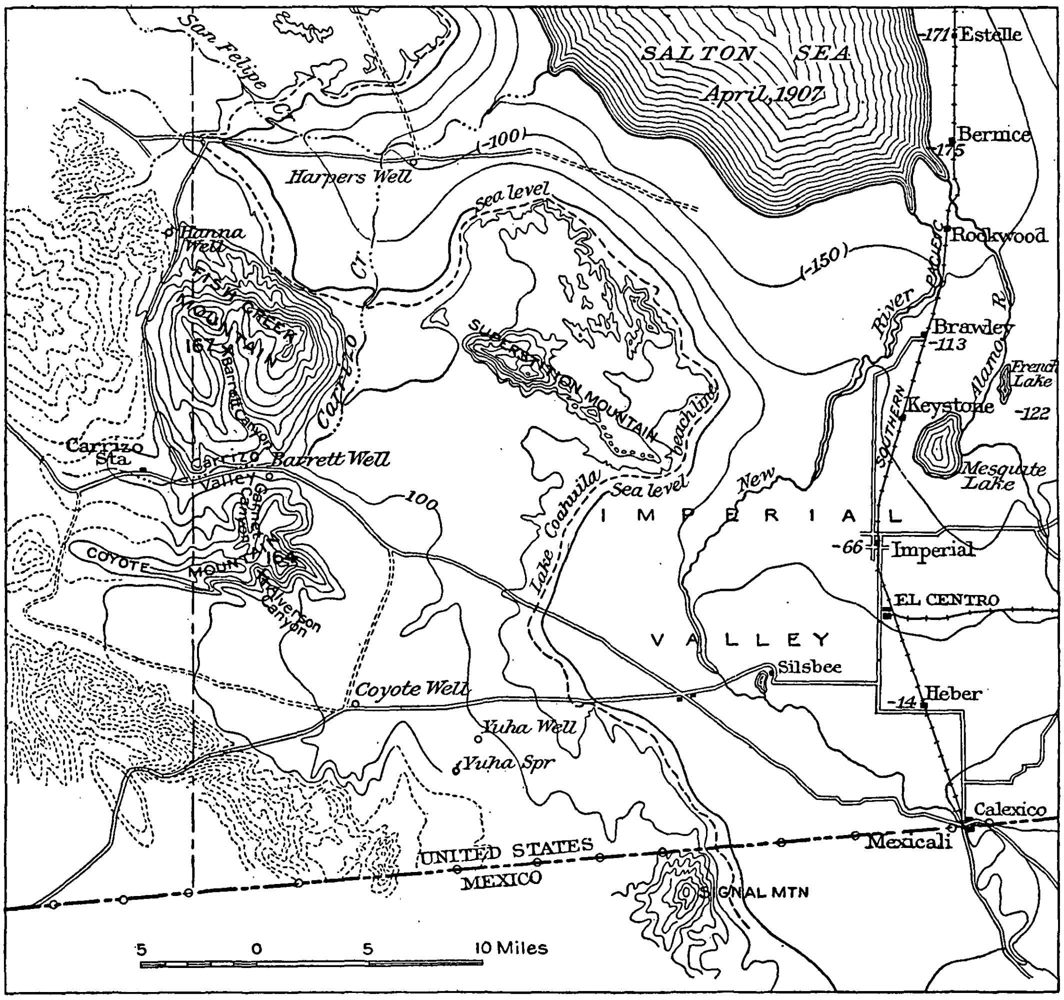


FIGURE 43.—Sketch map of Coyote Mountain, Cal., and vicinity, showing localities in Alverson and Barrett canyons where fossil corals were collected. (After Mendenhall.)

Black and Carrizo mountains, known also as Fish Creek and Coyote mountains, are eastern outliers of the Peninsula Range that separates the depression occupied in part by the Gulf of California from the Pacific Ocean. They are in southeastern California near the western edge of the

[1] Jour. Geology, vol. 18, pp. 336–355, 1910.

Colorado Desert and from 15 to 30 miles north of the international boundary. East of them the Colorado Desert, much of it below sea level, extends to the Colorado River, while to the west low ridges extend to the base of the main Peninsula Range.

The two masses are separated by the valley of Carrizo Creek. This stream rises in Mexico, flows north for several miles, through a high valley in the Peninsular Mountains, then descends to the desert level through a precipitous canyon. Nearly all of that part of its channel that lies within the desert is dry except during rare flood periods, when its waters join those of San Felipe Creek, north of Black Mountain, and eventually reach the Salton depression. At Carrizo Station, one of the relief stations of the old Butterfield stage line, a series of springs rise, and for 1 to 2 miles below this point flowing water is found in the creek bed except during the hottest period of summer.

The desert floor at the eastern base of the peaks is generally from 100 to 200 feet above sea level, but on the north side of Black Mountain the sea-level contour and the old beach of Lake Cahuilla, 40 feet above sea level, swing in against the mountain base. In the past the region has been rather difficult of access because of its remoteness from settlements and its aridity. With the colonization of the Imperial Valley since 1900 and the building of the branch railroad from Old Beach to Calexico, however, this condition has been greatly modified. Now Carrizo Station or Coyote Well may be reached by one day's drive from Imperial or El Centro, and supplies are readily secured at many points in the valley. The old roads from the desert to San Diego, the one running north of Carrizo Mountain by way of Julian and the other south of the mountain by way of Jacumba and Campo, are still much used for direct communication between the Imperial Valley and the coast, although the Campo road below Mountain Springs is rough and after storms is nearly impassable.

GEOLOGIC RELATIONS.

The following is Mendenhall's account of the broader geologic relations within the area:

Carrizo [Coyote] and Black [Fish Creek] mountains are islands of granitic and metamorphic rocks which rise through encircling terranes of later sediments and volcanics. These later beds are Miocene and younger, and the unconformity which exists between them and the older rocks upon which they lie is profound. The time interval represented by this unconformity is not known, because the age of the altered rocks below it is a matter of uncertainty. Fairbanks [1] expresses the opinion that they are Carboniferous or older, the opinion being based presumably upon their general resemblance to upper Paleozoic socks in other parts of California and upon the aspect of rome shells found in a float piece of siliceous limestone. Accepting this determination as the best possible in the state of our knowledge, we must conclude that the Triassic, Jurassic, and Cretaceous systems are without depositional representatives in this region. Either the Carrizo and Black Mountain areas were land masses subject to erosion during this interval or the evidence of such periods of deposition as intervened was later removed by erosional processes.

The Miocene seems to have been inaugurated by volcanic activity. On the southern slopes of both Carrizo and Black Mountains are bedded tuffs, volcanic conglomerates, and less extensive masses of dark lavas of andesitic aspect. On Black Mountain there are distinct sandstones interbedded with these and directly upon them lie the Miocene coral reefs. In Alverson Canyon, which drains south from Carrizo Mountain, red vesicular lavas are succeeded by green and lavender sandstones and conglomerates, whose constituent materials are volcanic, and these in turn grade into conglomerates with a diminishing proportion of volcanic pebbles. Above them are quartz conglomerates, tawny sandstones, and finally soft greenish-yellow clay shales.

An unconformity which is not especially conspicuous exists in the Miocene between the sandy shell-bearing beds, 100 feet or less in thickness, which immediately overlie the volcanics or the metamorphics, and the great mass of shales, greenish or yellowish at base, pink or pale red in general color tone toward the top, which form the badland area that is especially well developed between Black and Carrizo mountains. Finally, across the planed edges of these shale beds, a sheet of river cobbles, well rounded, has been distributed unconformably throughout the Carrizo Valley. They are probably Pleistocene but are earlier than the silts, sands, and gravels, which represent the offshore and beach deposits of the lake which until recently has occupied the Colorado Desert. The latest erosion has left these old stream deposits stranded upon the remnants of the earlier valley floor at heights of from 100 to 200 feet above the present bed of Carrizo Creek.

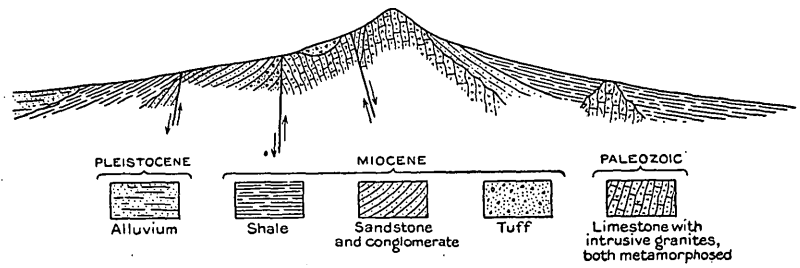


FIGURE 44.—Diagrammatic section across Coyote Mountain, Cal., by way of Alverson and Garnet canyons. (After Mendenhall.)

Figures 44 and 45 are copied from Mendenhall's paper, and the accompanying sketch geologic map (fig. 46) is taken from a paper by Kew.[2] It should be noted that the name Carrizo sandstone, shown on this map, has been in use since 1889 for a geologic formation of Eocene age exposed along and near the Rio Grande in Texas, and since 1891 for an Algonkian(?) formation in western Texas. The name therefore can not be properly applied to these California deposits.

[1] Fairbanks, H. W., California State Mineralogist Eleventh Rept., pp. 88-90, 1893.

[2] Kew, W. S. W., Tertiary echinoids of the Carrizo Creek region, in the Colorado Desert: California Univ. Dept. Geology Bull., vol. 8, p. 41, 1915.

GEOLOGIC HISTORY.

The following outline of the geologic history of the area is also taken from the article by Mendenhall:

The story of the development of this part of the country can not be read with any approach to accuracy as yet for any period beyond the Miocene. The rocks which represent earlier time are marmarized limestones, schists, and gneisses, as to whose age there is much doubt. The slight existing evidence points toward the Carboniferous as the period during which the limestones were deposited here. Whatever their age, their condition now indicates that their history previous to the Miocene was one involving deep burial and intense earth strain. They were upturned, intruded, and crystallized, uplifted and eroded

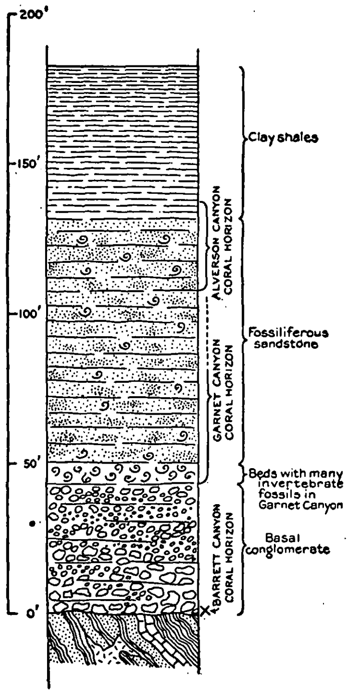


FIGURE 45.—Columnar section of rocks exposed in Garnet Canyon, Cal. (After Mendenhall.)

into a mountainous topography, and at the beginning of the late Miocene formed islands in a sea teeming with life. Volcanic forces were active at this time, and the flanks of the old land mass are partly buried under the effusive material which issued then, and the muds and the littoral whose fragments were supplied from volcanic sources are conspicuous at many points. But as the period advanced volcanism ceased, and the present Carrizo and Black mountains were surrounded and perhaps for a part of the time were submerged beneath a clear sea in which the myriad forms of the life of the period swarmed. Still later in the Miocene the character of the sea changed. Instead of clear, salt water, some realignment of forces caused great quantities of muddy, brackish water to spread about the old islands. Oysters of many forms, some of them of great size, some very tiny indeed, flourished. The heavy silts of these muddy waters accumulated to great depths as the land subsided. Finally the waters withdrew, presumably because of reelevation, and the region was land again as it had been before, and the shells of many of the creatures which had lived in the clear and then in the muddy waters were preserved in the accumulated sediments. As the sea withdrew the destructive forces of weathering and the erosive forces of wind and running water became active. The clays which had accumulated were now dry and were cut away again by these forces. The process was not long continued and the plain was not completed, those clay areas which were capped by protecting sandstones remaining as monadnocks above the wide valley floor. This valley, occupied by an earlier vigorous ancestor of Carrizo Creek, was strewn with rounded river cobbles brought from the higher mountains to the west. South and east of Carrizo Mountain large areas seem to have been reduced at this period well toward the condition of a peneplain. This plain lies perhaps 200 feet above the later Pleistocene lake level, with which it seems to have no connection. It is regarded as an earlier independent feature, perhaps Pliocene in age.

After the formation of this partially planed surface over the soft rocks of Carrizo Valley some change, either in the relations of land and sea or of climatic conditions, enabled the streams to dissect it again. The result of this dissection, which may well have been contemporaneous with the last occupancy of the Colorado Desert by the Gulf of California, is seen in the Carrizo Creek badlands of to-day.

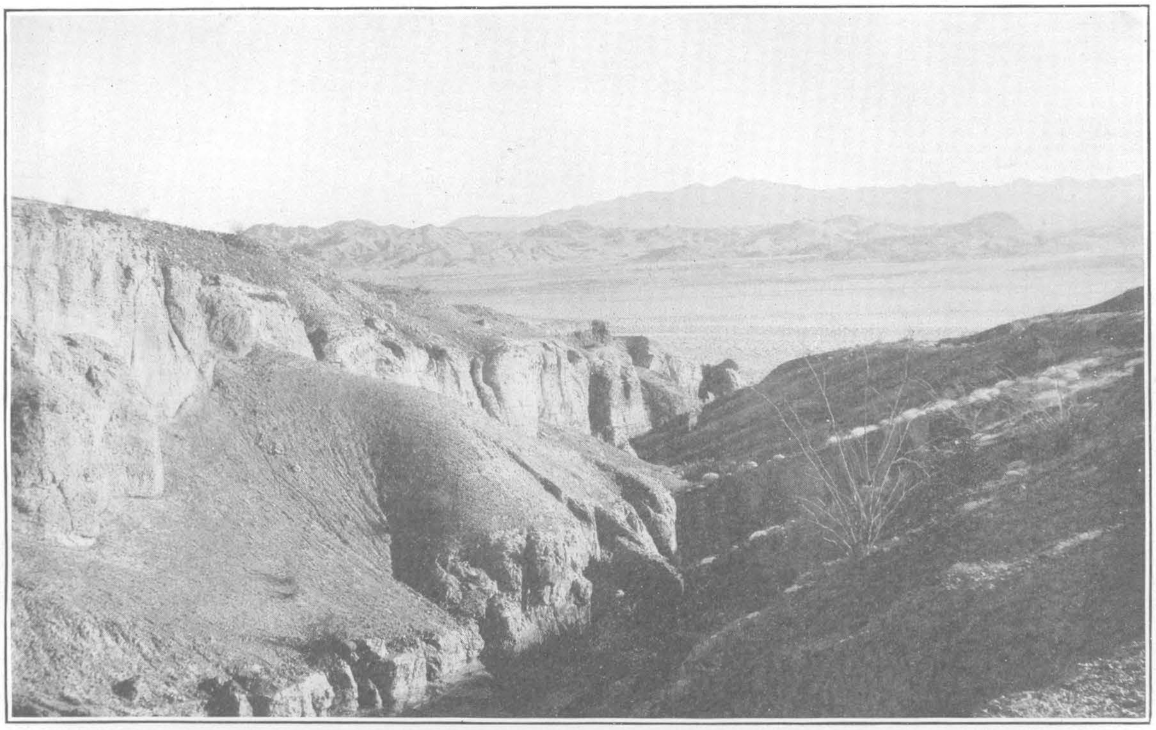
The last important element in the development of the geography of this part of the desert was the formation and the disappearance of the desert lake. So late is it that the calcium carbonate incrustations which it left on its western shore show but little effect of erosive or solvent action since the waters left them, and the sandy beach, molded by the waves of the lake upon the alluvial fans which formed a large part of its shores, is still well enough preserved to be readily traced. Only the most modern gullies have cut it away. At one point a low sea cliff notched by the waves in steep alluvial-fan material still stands, as perfectly preserved as though the waters had just withdrawn.

THE CORALLIFEROUS BEDS.

The fossil corals occur in that part of the columnar geologic section designated "Miocene conglomerates," by Mendenhall. The following is his description of these beds:

In the lower part of Alverson Canyon a heavy conglomerate bed 120 to 130 feet thick overlies a series of tuffaceous strata. This bed is composed of coarse material at the base but becomes finer at the top. It is only moderately hard, and along its upper margin is an abundantly fossiliferous horizon. Splendid coral heads are embedded in these sandstones, and more delicate forms are found at the base of the superjacent sandy shales. These corals with the molluscan remains that accompany them, all of which await detailed examination and determination, prove the age of the inclosing rocks to be upper Miocene. [See Pl. XCII.]

On the north slope of Carrizo [Coyote] Mountain, about the head of the easternmost arroyos which are tributary to Garnet Canyon, another series of fragments of a well-



A. VIEW LOOKING DOWN ALVERSON CANYON FROM A POINT NEAR ITS HEAD.

Coyote Wells Valley in the middle distance. Fossil corals and mollusks are found all along the canyon in sandstones overlying shales.

B. VIEW LOOKING N. 35° W. ACROSS THE MOUTH OF ALVERSON CANYON, FROM COYOTE WELLS VALLEY.

The fossiliferous Pliocene beds through which the shallow canyon is cut are shown in the middle ground.

VIEWS OF ALVERSON CANYON, IMPERIAL COUNTY, CAL.

Photographs and explanations by W. C. Mendenhall.

developed basal conglomerate are encountered. They extend well up the slopes of the older metamorphic rocks which form the axis of the mountain and dip away from it toward the north or northeast at the rate of 20° or 30°. Being more resistant to weathering agencies than the soft overlying shales, these have been stripped from the sand- spread out over the sandstones were deposited directly upon the metamorphic rocks that form the core of the mountain and must at one time have formed the bottom and shores of the Miocene sea. The simplest interpretation of this relation is to suppose that before that change of conditions was complete which substituted muddy

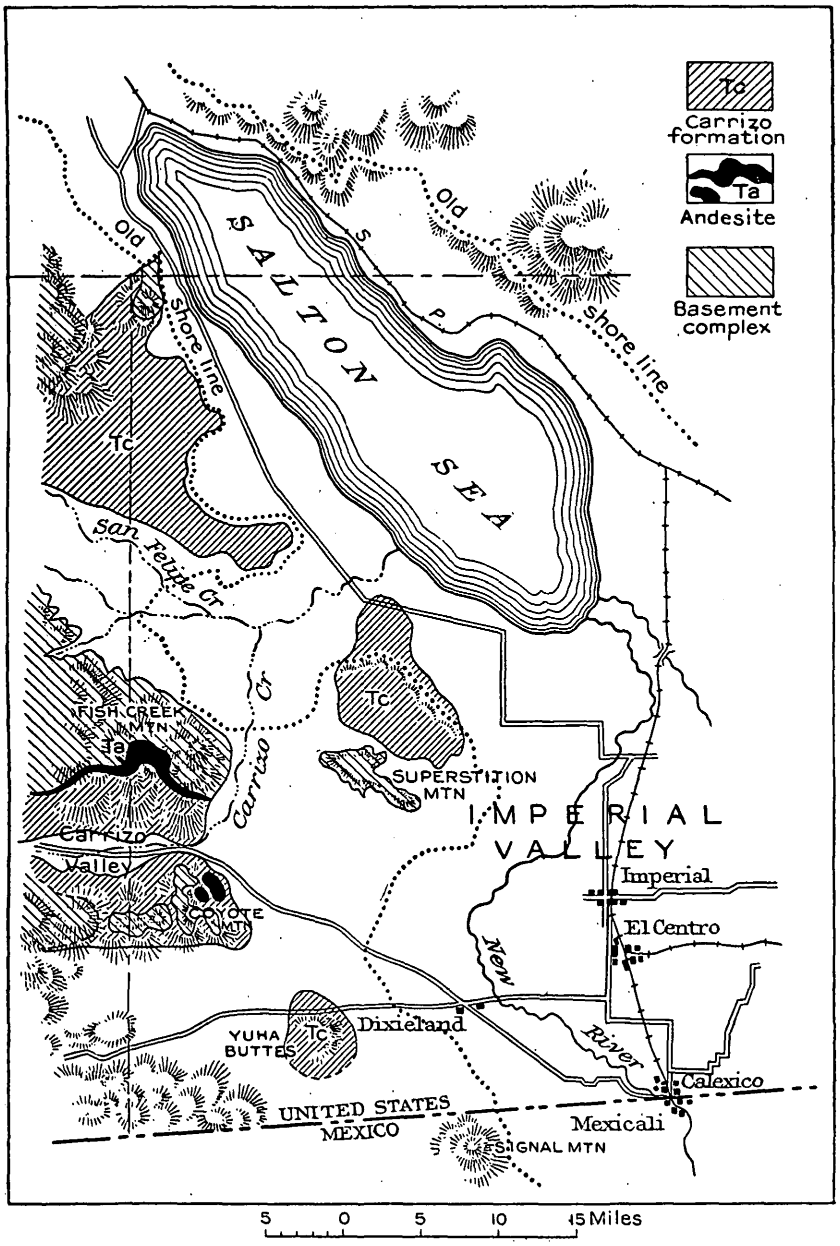


FIGURE 46.—Geologic sketch map of the southwestern part of the Colorado Desert, Cal., north of the Mexican boundary line, showing position of the geologic formations. Areas in the valleys represented without formational symbol are occupied by Pleistocene lake beds and alluvium. (After Kew.)

stones at many points so that the old Miocene beach, its sands indurated and its teeming life preserved only in fossil form but yet exhibiting much the aspect and much the same relations which existed at the time of its deposition, is revealed for the modern student's inspection. These basal sands are not always found where their horizon is exposed. In many places the fine clays that were brackish water with oyster colonies for clear sea water and marine life, the sands of the earlier beach had been swept away, so that there is unconformity, without discordance, or at least without marked discordance in dips, and without a great time interval between the deposition of the sands and the deposition of the muds. The other hypothesis, namely, that these beach sands and the muds were deposited contemporaneously, because of differing local conditions, is made difficult to apply because the two physically different terranes overlie the basement rocks at very closely adjacent points, with no obvious explanation as to why such different conditions should have prevailed so near together.

The heavy sandstones occur at a number of places along the north slope of Carrizo Mountain, east of the head of Garnet Canyon. Many arroyos are incised in them, the stream channel in some cases being a mere notch but a few feet wide and 100 or more deep. Fossils, however, have not been reported in numbers except at the head of Garnet Canyon.

At the head of Barrett Canyon, which drains south from Black Mountain, the same general relations prevail that have been described in the area a dozen miles to the south, on the slopes of Carrizo Mountain. But the fragments of the basal beds of the Miocene are even more widely scattered, and the sandstones and conglomerates are not so fully developed.

About 4½ miles above the mouth and one-half mile above the forks of the arroyo the basal beds of the Miocene flank the older rocks and extend across the valley from the west fork to the east fork. Dips here are 20°–40° S.—that is, away from the mountain. The beds are not so thick as on Carrizo Mountain but are succeeded, as is the case there, by soft yellow shales.

About a mile above this point, in a little cove at the head of a small western tributary of Barrett Creek, other outcrops of basal sandstone and conglomerate, not more than 10 feet thick, occur with the underlying igneous rocks all about them. Near this outcrop is a fossil coral reef lying upon the lavas and isolated from all the other sedimentaries. A half mile farther north a sheet of sandstone, folded into a basin and thus somewhat protected from erosion, still exists. Doubtless many other similar fragmental exposures would be revealed by more extended search. [See Pl. XCIII.]

The collections of fossil corals were obtained from localities numbered 164 and 167, respectively, by Messrs. Mendenhall and Bowers. The positions of these localities are platted on the map (fig. 43, p. 356). Mendenhall describes them as follows:

Nos. 164 and 166 are from Alverson Canyon and the head of Garnet Canyon on the south and north slopes, respectively, of Carrizo [Coyote] Mountain. The horizons are identical, being in each case the sandstones which form the upper part of the arenaceous series at the base of the Miocene. These are the most conspicuous fossil localities in the region. The shells or their casts have weathered out and strew the slopes in great profusion. Corals, echinoids, Ostrea, pectens, Strombus, and Malea are everywhere. The matrix, however, is coarse and only large and robust types are well preserved. The locality has been noted by prospectors generally because the occurrences are so conspicuous. [Views shown on Pl. XCII.]

No. 167. This collection consists of corals almost entirely. The fossil reef is near the head of Barrett Canyon and lies directly upon the igneous rocks which served as a basement for Miocene sedimentation at this point. Whatever later beds may have originally covered it have been stripped away, so that the old reef is now isolated. [View shown on Pl. XCIII.] There can be little doubt, however, that its position is at the base of the Miocene series and substantially equivalent to that of Nos. 164 and 166.

No. 164 of Mendenhall and Bowers is entered in the United States Geological Survey register of localities at which Cenozoic invertebrates have been collected as No. 3923; and No. 167 is entered there as No. 7616.

The observations recorded in preceding paragraphs show that the reef corals grew up unconformably on a basement during a period of submergence that followed a period when the basement stood above sea level. These relations of vigorous coral growth to change of sea level have been found to prevail in so many areas where reef corals thrive that they appear to be general.[1] The deposits in which the corals are embedded are largely arenaceous, and the reefs ultimately were probably killed by burial beneath sediment, as suggested by Mendenhall. At the time the reefs flourished there was, of course, shallow water in the area where their remains are now found, and the temperature probably averaged about 21° C. (70° F.) during the coldest months of the year.[2]

SIGNIFICANCE OF THE CORAL FAUNA.

GENERIC AFFINITIES OF THE FAUNA OF CARRIZO CREEK.

The discussion of this fauna may be best introduced by placing in parallel columns the names of the genera represented on Carrizo Creek, those of the shoal-water corals known to occur along the west coast of Central America from the Gulf of California to the Bay of Panama, and those of the genera found living in shoal water in the Floridian, Antillean, and eastern Central American region. The data for the column headed "Guaymas to Panama" are taken from a paper by Verrill.[3]

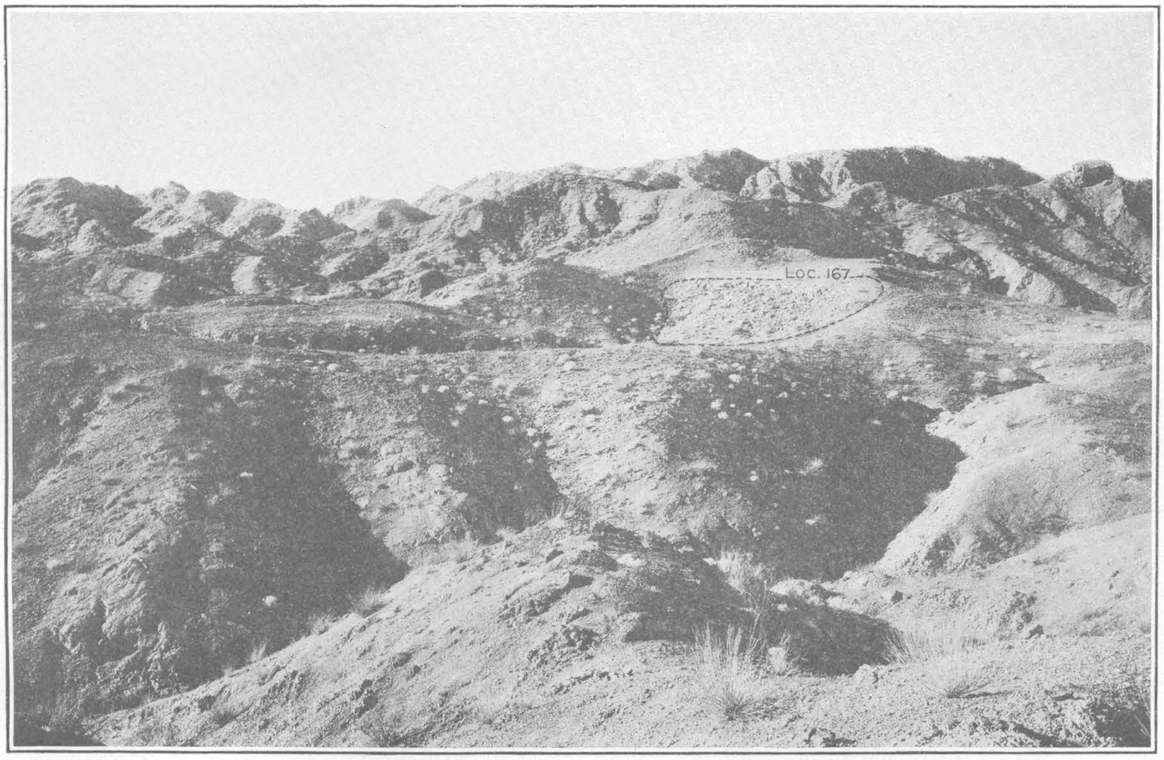
[1] See Vaughan, T. W., Science, new ser., vol. 41, pp. 508, 509, Apr. 2, 1915; Geol. Soc. America Bull., vol. 26, p. 58, 1915; Vaughan, T. W., and Shaw, E. W., Carnegie Inst. Washington Yearbook No. 14, pp. 237, 238, 1916.

[2] For recent discussions of the ecologic conditions necessary for the formation of coral reefs, see Vaughan, T. W., Physical conditions under which Paleozoic coral reefs were formed: Geol. Soc. America Bull., vol. 22, pp. 238–252, 1911; Results of investigations of the ecology of the Floridian and Bahaman shoal-water corals: Nat. Acad. Sci. Proc., vol. 2, pp. 95–100, 1916; Temperature of the Florida coral-reef tract: Carnegie Inst. Washington Pub. 213, 1917.

[3] Verrill, A. E., On the geographical distribution of the polyps of the west coast of America: Connecticut Acad. Arts and Sci. Trans., vol. 1, pp. 562, 563, 1870.

A. THE BARRETT CANYON FOSSIL CORAL REEF.

The reef is shown in the right middle ground. At this locality the corals rest directly upon the effusive rocks, which rise higher and form the surrounding hills.



B. VIEW OF FOSSIL CORAL LOCALITY NEAR HEAD OF BARRETT CANYON.

The basal beds of the Pliocene sandstones overlie effusive rocks and dip to the right in the foreground of the view. The coral reef lies immediately upon the effusive rocks. Coyote Mountain in the background.

VIEWS OF BARRETT CANYON, IMPERIAL COUNTY, CAL.

Photographs and explanations by W. C. Mendenhall.

Coral genera represented at Carrizo Creek, Cal., and on the west and east sides of Central America.

Genus.	Carrizo Creek.	Guaymas to Panama.	Caribbean and Mexican Gulf region.
Paracyathus		×	×
Pocillopora		×	
Madracis			×
Oculina			×
Stephanocœnia			×
Eusmilia	×		×
Dichocœnia	×		×
Meandrina			×
Dendrogyra			×
Astrangia		×	×
Phyllangia		×	×
Ulangia		×	
Cladocora			×
Orbicella			×
Solenastrea	×		×
Favia			×
Mæandra	×		×
Manicina			×
Mussa s. s.			×
Mussa (Isophyllia)			×
Mussa (Acanthastrea)			×
Mycetophyllia			×
Fungia		×	
Agaricia			×
Pavona		×	
Stephanaria		×	
Siderastrea	×		×
Dendrophyllia		×	
Astropsammia		×	
Rhizopsammia		×	
Acropora			×
Montipora		×	
Porites	×	×	×
Total (33 genera).	6	13	24

Six genera are included in the fauna of Carrizo Creek, only one of which (Porites) is at present known to occur on the west coast of America, though all six are found in the Gulf of Mexico and the Caribbean Sea. Of 13 shoal-water genera at present represented by species on the west coast of Central America, only 4 are represented on the east coast. One of the remaining 9 genera (Dendrophyllia) is found in the western Atlantic in water over 50 fathoms deep, but any similarity suggested by its presence may be offset by the fact that it is essentially worldwide in distribution. The genus Endopachys occurs in water 39 fathoms deep in the Gulf of California but is unknown in the West Indian and Floridian area. The table lists 24 West Indian genera, 4 of which also occur on the west side of Central America. The number 24 might be somewhat increased, as Verrill has described a species of Cyphastrea from the Bahamas,[1] under the name *Cyphastrea nodulosa*, and I have in my possession an undescribed species of Oulophyllia from the Bahamas, sent to me by Miss A. M. Boynton, of Nassau. The Oulophyllia is strikingly similar to *O. bonhourei* Gravier,[2] from French Somaliland. Both Cyphastrea and Oulophyllia are widely distributed in the Indo-Pacific, but they are not known to occur along the Pacific coast of Central America. Two West Indian shoal-water genera, Oculina and Cladocora, occur in deeper water off the Pacific coast.

The table shows the marked difference between the coral faunas on the two sides of Central America and indicates that the affinities of the fauna of Carrizo Creek are with the fauna of the Mexican Gulf and Caribbean area. Have the faunas on the two sides of Central America always been so distinct? An attempt is made to answer this question in the following discussion.

GEOLOGIC HISTORY OF THE CORAL FAUNAS OF THE SOUTHEASTERN UNITED STATES AND THE WEST INDIES.

EOCENE AND LOWER OLIGOCENE FAUNAS.

The data presented in the following table are largely taken from my monograph on the Eocene and lower Oligocene coral faunas of the United States,[3] revised so as to represent the present stage of knowledge.

Geographic distribution of Recent genera of corals found also in the Eocene and lower Oligocene deposits of the southern United States.

Genus.	Distribution.
Flabellum	Almost universal.
Sphenotrochus	Mediterranean Sea and North Africa, coast of Brazil, European coasts of north Atlantic Ocean, South Australian coast.
Platytrochus	Australian seas (?).
Turbinolia	Caribbean Sea, Indo-Pacific.
Trochocyathus	West Indies, South American seas, Indo-Pacific.
Paracyathus	Mediterranean Sea, Caribbean Sea, north Atlantic Ocean, Indian Ocean, Pacific Ocean, California (Pearl Islands).
Caryophyllia	Littoral and deep sea, very general.

[1] Verrill, A. E., Connecticut Acad. Arts and Sci. Trans., vol. 11, p. 107, pl. 31, figs. 2, 2a, 2b, 1902.

[2] Gravier, Charles, Inst. océanogr. Annales, fasc. 3, p. 49, pl. 4, figs. 25, 26; pl. 5, figs. 27, 28, 1911.

[3] U. S. Geol. Survey Mon. 39, pp. 33, 34, 1900.

Geographic distribution of Recent genera of corals found also in the Eocene and lower Oligocene deposits of the southern United States—Continued.

Genus.	Distribution.
Oculina	Florida, Caribbean Sea, Bermudas, Indian Ocean, Pacific Ocean.
Madrepora	Atlantic Ocean, Caribbean Sea, Mediterranean Sea, Indo-Pacific.
Stylophora	Red Sea, Indo-Pacific.
Madracis	Madeira, Florida, Caribbean Sea, Brazil, Adriatic Sea, Indo-Pacific.
Parasmilia	Caribbean Sea, Philippines.
Astrangia	Florida, Central America, East Indies, Panama Bay, east and west coasts of North America, Strait of Magellan.
Dichocœnia	West Indies.
Siderastrea	Caribbean Sea, islands off west coast of Africa, Indo-Pacific.
Balanophyllia	Caribbean Sea, Mediterranean Sea, English Channel, St. Helena, Madeira, California, Indo-Pacific.
Eupsammia	Chinese seas.
Endopachys	West coast of America, Pacific.
Dendrophyllia	Caribbean Sea, Atlantic Ocean, Cape Verde, Madeira, Mediterranean Sea, Bay of Panama, California, Indo-Pacific.
Goniopora	Indo-Pacific.

The foregoing table shows that in their generic relations the Eocene and lower Oligocene corals of the southeastern United States are about equally divided between the Atlantic and the Indo-Pacific regions. There is a great resemblance between the species of Paracyathus, Balanophyllia, and Siderastrea now found in the West Indian region and the Eocene species of the same genera; but Platytrochus, Stylophora, Eupsammia, Endopachys, and Goniopora are not represented by known species from the Atlantic Ocean.

The difference between the Eocene faunas of the southern United States and the Eocene fauna of the West Indies is striking, as no known species is common to the two regions. The difference is probably due to two causes. One is climatic; the area in the United States lay so far north that except during early Midway and Vicksburg time it was not within the zone of truly tropical conditions. During Wilcox and Claiborne time and the earlier part of Jackson time the sea was warm-temperate but not actually tropical. For this reason reef corals did not abound in the southern United States during the Eocene epoch except in early Midway time. In the Jackson epoch there was a gradual recurrence of tropical conditions and during lower Oligocene time a well-developed coral reef, composed of species of Stylophora and Goniopora was formed at Salt Mountain, Ala. The other cause of faunal difference lies in the difference in stratigraphic history, as the known Eocene deposits of the West Indies include representatives of only the upper groups of the series. Because according to present knowledge the Antilles contain no Eocene deposits stratigraphically corresponding to the Midway, Wilcox, and probably Claiborne groups of the United States, they are supposed to have stood above sea level during the period of deposition of these groups.

There is a fairly rich Eocene coral fauna on the Island of St. Bartholomew and a scantier fauna is known from Jamaica. The principal literature on these faunas is cited below.[1]

The determination of the Eocene age of the St. Bartholomew coralliferous deposits is based on evidence of several kinds. A part of the evidence consists in my discovery in association with the coral fauna of a stellate orbitoidal foraminifer, closely resembling in general aspect a species I found in 1900 on Flint River near Bainbridge, Ga. Dr. Joseph A. Cushman has studied both the St. Bartholomew and the Flint River specimens and informs me that they belong to the genus Orthophragmina, which is considered to indicate positively an Eocene age.

In 1904 Prof. A. G. Hogböm, of the University of Upsala, sent to me for study the entire collection obtained on St. Bartholomew by Prof. Cleve,[2] and during February, 1914, I spent eight days studying and collecting on the island.[3] The following list of genera is based upon both these collections, and I have added the names of four genera represented in Jamaica (the names followed by "J" in the table) but not known in St. Bartholomew.

[1] Cleve, P. T., On the geology of the northeastern West India Islands: K. svenska Vet.-Akad. Handl., vol. 9, No. 12, p. 24, 1872.
Hill, R. T., The geology and physical geography of Jamaica: Harvard Coll. Mus. Comp. Zool. Bull., vol. 34, pp. 123-137, 1879.
Vaughan, T. W., Some Cretaceous and Eocene corals from Jamaica: Harvard Coll. Mus. Comp. Zool. Bull., vol. 34, pp. 227-256, pls. 36-41, 1899; Study of the stratigraphic geology * * * of the smaller West Indian Islands: Carnegie Inst. Washington Yearbook No. 13, pp. 358-360, 1915; [Present status of the geologic correlation of the Cretaceous and Tertiary formations of the Antilles]: Washington Acad. Sci. Jour., vol. 5, p. 489, 1915; Study of the stratigraphic geology * * * of the smaller West Indian Islands: Carnegie Inst. Washington Yearbook No. 14, pp. 368-373, 1916.

[2] P. M. Duncan's report on this collection was published in London Geol. Soc. Quart. Jour., vol. 29, pp. 548-565, pls. 19-22, 1873.

[3] A minor grant from the Carnegie Institution of Washington enabled me to do geologic field work and make extensive collections in Antigua St. Bartholomew, and Anguilla during February and March, 1914. The discussion of the fossil corals of these islands herein presented is based largely on the collections made at that time.

Corals in the upper Eocene of St. Bartholomew and Jamaica.

Genus.	Atlantic Ocean.	Indo-Pacific.	Extinct.
°Placotrochus		×	
°Asterosmilia	×		
°Trochosmilia			×
°Stylophora		×	
°Astrocœnia	×		
°Antillia		×	
°Favia	×	×	
°Goniastrea		×	
°Mæandra	×	×	
Leptoria		×	
°Syzygophyllia		×	
Trochoseris (J)			×
Mesomorpha (J)			×
Antilloseris			×
Physoseris			×
Protethmos [a]			×
Metethmos [a]			×
°Actinacis			×
Dendracis (J)			×
Multicolumnastræa (J)			×
°Goniopora		×	
Total (21 genera)	4	9	10

[a] These two genera were described by Gregory (Palæontologia indica, 9th ser., vol. 2, pt. 2, pp. 162-167, 1900) from specimens obtained in the Jurassic of Cutch, India, and appear to be represented in the Eocene of St. Bartholomew, but the generic identifications are not beyond question.

Of the 21 genera named in the table 4 are represented to-day in the Atlantic Ocean, 2 of them only in the Atlantic; 9 are represented in the living Pacific fauna, 7 of them only in the Pacific; and 10 genera are so far as known extinct. Although further study may add to the list, its essential indications will not be changed. The upper Eocene fauna of St. Bartholomew contains representatives of 11 living genera of corals, and 7 of these are, according to our present knowledge, now confined to the Indo-Pacific region. Therefore its affinities are more with the Indo-Pacific fauna of to-day than with that of the Atlantic. The genera whose names are preceded by a degree mark (°) also occur in deposits of Oligocene age.

UPPER OLIGOCENE FAUNAS.

Although there is much similarity in the upper Oligocene faunas, there are at least four recognizable horizons at which they occur in the southeastern United States. These are, named in stratigraphically ascending order, as follows: (1) Basal part of the Chattahoochee formation, in the reefs near Bainbridge, Ga.; (2) the silex bed of the Tampa formation, near Tampa, Fla., and at numerous localities in Florida and southern Georgia; (3) the Chipola marl member of the Alum Bluff formation; (4) the Oak Grove sand member of the Alum Bluff formation. Although the descriptions of these faunas are not quite complete, their essential characteristics have been ascertained. The following is a list of the coral genera:

Coral genera represented in the upper Oligocene deposits of Georgia and Florida.

Genus.	Basal Chatta-hoochee.	Silex bed, Tampa.	Chipola marl.	Oak Grove sand.	Atlantic.	Pacific.	Extinct.
Astrhelia				×			×
Stylophora	×	×	×			×	
Stylocœnia	×						×
Astrocœnia	×				×		
Antillia	×	×	×			×	
Orbicella	×	×			×	×	
Solenastrea		×			×	×	
Galaxea		×				×	
Favites	×					×	
Mæandra		×			×	×	
New genus			×				×
Syzygophyllia		(?)				×	
Siderastrea	×	×			×	×	
Mesomorpha	×						×
Diploastrea	×					×	
Endopachys		×				×	
Acropora		×			×	×	
Actinacis	×						×
Astreopora	×					×	
Porites		×			×	×	
Goniopora	×	×	×			×	
Alveopora	×	×				×	
Total (22 genera)	13	13	4	1	7	16	5

Of 13 genera represented in the basal Chattahoochee, 2 occur in the living faunas of both the Atlantic and the Indo-Pacific, 7 occur only in the Indo-Pacific, 1 only in the Atlantic, and 3 are extinct. The silex bed of Tampa contains 13 genera, 7 of which are at present confined to the Indo-Pacific, 6 are common to the Atlantic and Indo-Pacific, and none is extinct. The Chipola marl contains 4 genera, 3 of which persist in the Indo-Pacific but are not known in the Atlantic, and 1 is extinct. Only 1 genus, Astrhelia, has been found in the Oak Grove sand. It is represented in the lower Miocene of Maryland, but is now extinct. Tropical marine temperatures prevailed as far north as southern Georgia throughout the deposition of the Chattahoochee and Tampa formations, but during the period when the upper beds of the Alum Bluff formation were being laid down the waters cooled and living upper Oligocene coral reefs vanished from Georgia and Florida. The cooler Miocene epoch followed, and it was succeeded by the warm Pliocene epoch, during which reef corals flourished in southern Florida, but, as will later be made clear, they represent a different fauna, for during the Miocene every coral of Pacific facies had disappeared, and the Pliocene fauna is of purely Atlantic affinities.

The West Indian and Central American upper Oligocene faunas represent several different horizons. (See references to my papers, p. 362.) One of the faunas, that at the base of the "marl formation" of Antigua (the Antigua formation of J. W. Spencer), is almost identical with that at the base of the Chattahoochee formation near Bainbridge, Ga. Beds representing the same horizon are exposed 4 miles west of Lares, Porto Rico; and beds representing the same or nearly the same horizon occur at the base of the bluff at Crocus Bay, on the north side of the island of Anguilla. The higher beds in the Crocus Bay exposures seem to correspond stratigraphically with the Emperador limestone of Panama. The fauna of Bowden, Jamaica, is nearly related to this higher fauna but may be somewhat younger. The following table presents the list of genera for Antigua, Anguilla, Empire (Panama), and Bowden (Jamaica).

Genera of corals in the upper Oligocene of Antigua, Anguilla, Empire (Panama), and Bowden (Jamaica).

[Genera whose names are followed by (L) occur also 4 miles west of Lares, Porto Rico.]

Genus.	Antigua.	Anguilla.	Empire, Panama.	Bowden, Jamaica.	Atlantic.	Pacific.	Extinct.
Placocyathus				×		(?)	
Placotrochus				×		×	
Sphenotrochus				×	×	×	
Trochosmilia	×						×
Asterosmilia	×			×	×		
Stylophora	×	×	×	×		×	
Pocillopora	×					×	
Styloccenia	×	×					×
Madracis				×	×	×	
Astroccenia (L)	×				×		
Antillia	×	×		×		×	
Orbicella (L)	×	×	×		×	×	
Cladocora		×			×	×	
Diplothecastrea	×						×
Favites	×					×	
Goniastrea			×			×	
Lamellastræa	×						×
Thysanus				×			×
Teleiophyllia				×			×
Mæandra (L)	×				×	×	
Manicina	×				×		
Syzygophyllia				×		×	
Agaricia (L)		×			×		
Pavona	×		×			×	
New genus	×	×					×
Leptoseris	×					×	
Haloseris	×					×	
Siderastrea (L)	×	×		×	×	×	
Diploastrea	×					×	
Acropora	×		×	×	×	×	
Astreopora (L)	×		×			×	
Porites	×	×	×	×	×	×	
Goniopora (L)	×	×	×	×		×	
Alveopora	×					×	
Total (34 genera)	24	10	8	14	12	22+?1	7

The Antiguan fauna contains 24 genera, of which only 5 are extinct; of the 19 genera represented by living species 2 are now confined to the Atlantic, 5 are represented in both the Atlantic and Pacific, and 12 (50 per cent) are at present confined to the Pacific. The fauna is predominantly Pacific. Of the 9 genera on Anguilla 3 are at present confined to the Pacific. Of the 8 genera from Empire, Panama, 5 are represented by living species only in the Pacific. Of the 14 genera represented at Bowden, Jamaica, 2 are extinct, 2 are at present confined to the Atlantic, 5 are common to the Atlantic and Pacific, and 6 (if Placocyathus is included) are confined to the Pacific. Stephanocœnia is found at Bowden and appears to have been collected in place. It is also Pleistocene and Recent in the West Indies. The living *Stephanocœnia intersepta* (Esper) is the type of the genus.

Because of the known presence of species of Lepidocyclina (identified by J. A. Cushman) in the base of the Chattahoochee formation near Bainbridge, Ga., in the Antigua formation in Antigua, in the fossil reefs of Anguilla, and in the Emperador limestone of Panama, most paleontologists will agree as to the Oligocene age of these deposits, and as the beds exposed 4 miles west of Lares, Porto Rico (the Pepino formation of Hill) contain essentially the same coral fauna as the Antigua formation, their Oligocene age will probably be conceded.

It should be stated here that H. Douvillé [1] refers *Lepidocyclina canellei* Lemoine and R. Douvillé and *L. chaperi* Lemoine and R. Douvillé, both of which occur in the Culebra formation of the Canal Zone, to the Aquitanian, which he considers to be Miocene. The Culebra formation immediately underlies the Emperador limestone, in which the principal reef-coral fauna of the Canal Zone is found in association with Lepidocyclina and other orbitoidal Foraminifera. The larger Foraminifera of the Canal Zone are described in a paper, now awaiting publication, by Dr. Jos. A. Cushman, who has almost completed descriptions of the species of Lepidocyclina and Orthophragmina from the southeastern United States and the West Indies.

Regarding the age of the formations belonging to the Apalachicola group but higher than the Chattahoochee formation in Georgia and Florida there is controversy, and the controversy extends to the age of the marl at Bowden, Jamaica, some paleontologists contending that these formations are of Oligocene age, others that they are of Miocene age. Berry [2] has recently discussed this subject, and his concluding remarks are as follows:

> There is thus no structural (diastrophic) evidence for drawing the Oligocene-Miocene boundary between the Chattahoochee and Alum Bluff formations, nor is there any floral or faunal evidence for such a boundary. There is such a break between the Vicksburg and Apalachicola groups, and the Alum Bluff is separated by an erosion unconformity from the overlying Choctawhatchee Miocene. It rests with invertebrate paleontology to determine whether or not the whole of the Apalachicola group shall be considered Miocene. Whatever may be the final verdict, it remains true that the flora preserved at Alum Bluff records the last phase of sedimentation before the area emerged from the sea and that the most profound break in Tertiary sedimentation in the southeastern United States, emphasized equally by epeirogenic, faunal, and floral changes, was at the end of Apalachicola time—that is, it is represented by the unconformity at the top of the Alum Bluff formation.

The Apalachicola group has an impressive unity for those who have had extensive field experience in studying it, and they will not readily sanction its dismemberment. Out of 13 genera, the Bowden marl contains 6 of Indo-Pacific affinities (Placocyathus, Placotrochus, Stylophora, Antillia, Syzygophyllia, and Goniopora) and 2 (Thysanus and Teleiophyllia) that are extinct. As the affinities of this coral fauna are predominantly Indo-Pacific, I am inclined to the opinion that it corresponds stratigraphically to the upper part of the Apalachicola group and is older than the Chesapeake group (Miocene) of the United States.

Apalachicolan time was terminated by the notable geologic events mentioned in the quotation from Berry.[3] These events led to a severing of the waters of the Atlantic from those of the Pacific by the establishment of land connection between North and South America. It seems that the extinction of the coral genera of purely Pacific affinities was effected by causes not understood but in some way related to these events, for these genera

[1] Les orbitoïdes de l'île de Trinité: Paris Acad. sci. Compt. rend., vol. 161, pp. 87-92, 1915; Les couches à orbitoïdes de l'isthme de Panama: Soc. géol. France Compt. rend. for Dec. 20, 1915, pp. 129-130.

[2] Berry, E. W., The physical conditions and age indicated by the flora of the Alum Bluff formation: U. S. Geol. Survey Prof. Paper 98, pp. 44-46, 1916 (Prof. Paper 98-E).

[3] For additional discussion of the subject see Vaughan, T. W., A contribution to the geologic history of the Floridian Plateau: Carnegie Inst. Washington Pub. 133, pp. 153-157, 1910; Vaughan, T. W., and Cooke, C. W., Correlation of the Hawthorn formation: Washington Acad. Sci. Jour., vol. 4, pp. 250-253, 1914.

are not present in the next younger important coral fauna of the southeastern United States.

MIOCENE FAUNA.

The Miocene coral fauna of the eastern and southeastern United States is poor both in genera and in species.[1] The genera are Paracyathus, Astrhelia, Astrangia, Septastrea, and a species described by Gregory[2] under the name *Prionastræa vaughani*, which perhaps should be referred to the genus Favites—a total of five genera. The marine waters of the Miocene in the southeastern United States, as Dall and others have pointed out, were cold as compared with the earlier Apalachicola and the later Pliocene sea, and Berry[3] has recently reconsidered this subject. Although the waters appear not to have been so cold as was formerly believed, they were too cold for reef corals, and such organisms disappeared from the eastern and southern parts of the continent during Miocene time.

PLIOCENE FAUNA.

Pliocene time was initiated by a recurrence of warm-water conditions, and with the change in climate a fairly rich reef-coral fauna established itself in Florida as far north as latitude 27°. It is especially well exposed within the area underlain by the Caloosahatchee marl. The following are the genera:

Corals in the Caloosahatchee marl (Pliocene).

Genus.	Atlantic.	Pacific.	Carrizo Creek, Cal.
Oculina	×	×	....
Dichocœnia	×	....	×
Meandrina	×	....	....
Phyllangia	×	×	....
Solenastrea	×	×	×
Septastrea (extinct).			
Thysanus (extinct).			
Mæandra	×	×	×
Siderastrea	×	×	×
Porites	×	×	×
Total (10 genera).	8	6	5

[1] See Vaughan, T. W., Maryland Geol. Survey, Miocene, pp. 438-447, pls. 122-129, 1904.

[2] Gregory, J. W., New species of Cladophyllia, Prionastræa, and Stylina: Annals and Mag. Nat. Hist., 7th ser., vol. 4, p. 458, figs. 2a, 2b, 1899.

[3] Berry, E. W., The physical conditions indicated by the flora of the Calvert formation: U. S. Geol. Survey Prof. Paper 98, pp. 61-73, 1916 (Prof. Paper 98-F).

The foregoing table shows that of 10 genera represented in the Caloosahatchee marl 2 are extinct, 8 persist in the living Antillean fauna, and 6 are common to the Atlantic and the Indo-Pacific. The species belonging to the 8 genera that are also Recent are either living or, with one exception, so near species at present living on the Florida and Bahama reefs that specific discrimination is difficult or doubtful. All the purely Indo-Pacific elements are lacking in this fauna, which, except for one of the two extinct genera (Septastrea) is typically Antillean. Of the 6 genera represented in the fauna of Carrizo Creek 5 also occur in the Caloosahatchee fauna, and all 6 are present in the living Antillean fauna.

PLEISTOCENE AND RECENT FAUNAS.

A list of the genera of corals at present living in the shoal waters of the West Indies, Florida, and Central America is given on page 361. Until now it has not been possible to distinguish between the Pleistocene and Recent faunas of the region, as all definitely identified Pleistocene species are also found living in the same region.

SUMMARY.

The data presented in the foregoing discussion show:

1. That during Eocene, lower Oligocene, and upper Oligocene time the coral faunas of the southeastern United States and the West Indies comprised three elements—(*a*) genera now extinct; (*b*) Recent genera which are now living only in the Indo-Pacific region; and (*c*) genera which persist in the western Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea, and some of which are also present in the living Indo-Pacific faunas.

2. That the sharp differentiation between the Atlantic and Pacific faunas took place between the end of Apalachicola time and the beginning of Pliocene time, and that since Pliocene time there has been only subordinate modification of the Atlantic fauna.[4]

[4] R. A. Daly's suggestion that this differentiation was due to lowering of marine temperature during Pleistocene glaciation (Am. Acad. Arts and Sci. Proc., vol. 5, pp. 169-170, 1915) can not be true, for the differentiation had taken place before Pliocene time.

3. That this differentiation was in some way related to diastrophic and other geologic events which occurred during Miocene time. The causes of the extinction of the Pacific elements are unknown. The problem is rendered more difficult because the reef corals of the Atlantic and Indo-Pacific conform to the same ecologic principles.[1] Mayer says in his paper on Torres Straits: "We must conclude that 'corals are corals,' and their behavior is essentially alike both in Florida and Australia."

4. That the systematic affinities of the fauna of Carrizo Creek are with the Caloosahatchee Pliocene of Florida and the Pleistocene and living faunas of the Antilles.

GEOLOGIC AGE OF THE FAUNA OF CARRIZO CREEK.

From statements already made it is obvious that there has been great uncertainty as to the geologic age of the fauna of Carrizo Creek. At first it was thought to be probably Cretaceous, later it was considered lower Miocene, after that it was referred to the upper Miocene, and the latest opinion is that it is Pliocene.

The following statement and list are quoted from Kew:[2]

> The age of the Carrizo formation[3] has not been definitely determined. Dr. Arnold[4] referred to it as equivalent to the upper Miocene or lower Pliocene Etchegoin formation of the San Joaquin Valley of middle California, correlating by means of the pectens. The echinoderm fauna seems to indicate a comparatively late age, as several of the forms are very closely related to the species living in the Gulf of California at the present time, and these species are presumed to change relatively rapidly. Whether this seemingly slow development is due to comparative isolation in a warm-water area is as yet not known. These questions can not be answered definitely until the fauna has been compared carefully with the Recent life from the Gulf of California.

[1] See references to my papers on p. 360. Also Mayer, A. G., An expedition to the coral reefs of Torres Straits: Pop. Sci. Monthly, vol. 85, pp. 209-231, 1914; Ecology of the Murray Island coral reef: Nat. Acad. Sci. Proc., vol. 1, pp. 211-214, 1915; Carnegie Inst. Washington Pub. 213, pp. 1 et seq., 1917.

[2] Kew, W. S. W., Tertiary echinoids of the Carrizo Creek region, in the Colorado Desert: California Univ. Dept. Geology Bull., vol. 8, pp. 46, 47, 1914.

[3] See footnote on p. 355.

[4] Science, new ser., vol. 19, p. 503, 1904; U. S. Geol. Survey Prof. Paper 47, p. 21, 1906; U. S. Geol. Survey Bull. 396, p. 44, 1909.

An approximate list of the fauna of the Carrizo formation, so far as determined, is as follows:

	Lower division, all localities.	Upper division.	
		Carrizo Valley.	Yuha Buttes.
PELECYPODA.			
Anomia subcosta Conrad	×	×	×
Anomia n. sp.	×	×	×
Arca n. sp. A	×	×	....
Arca n. sp. B	×	....	....
Cardium aff. C. quadrigenarium Conrad	×	....	....
Crassatellites sp.	×	....	....
Divaricata eburnea Reeve	×	....	....
Dosinia n. sp.	×	....	....
Glycymeris sp.	×	....	....
Hinnites gigantea n. var.	×	....	....
Lithodomus sp.	×	....	....
Metis alta Conrad	×	....	....
Ostrea heermani Conrad	×	....	....
Ostrea vespertina Conrad	×	×	×
Panope generosa Gould	×	....	....
Pecten carrizoensis Arnold	×	×	....
Pecten subnodosus n. var.	×	....	....
Pecten circularis n. var.	×	×	×
Pecten deserti Conrad	×	....	....
Pecten cerrosensis var. mendenhalli Arnold	×	....	....
Pecten keepi Arnold	×	....	....
Pecten n. sp.	×	....	....
Phacoides cf. P. sanctæcrucis Arnold	×	....	....
Pinna sp.	×	....	....
Pholas sp.	×	....	....
GASTROPODA.			
Architectonica sp.	×	....	....
Cancellaria sp. A	×	....	....
Cancellaria sp. B	×	....	....
Cassis sp.	×	....	....
Cerithium sp.	×	....	....
Conus sp. A	×	....	....
Conus sp. B	×	....	....
Dolium cf. D. ringens Sowerby	×	....	....
Neverita cf. N. recluziana Petit	×	....	....
Oliva cf. O. porphyria Linnæus	×	....	....
Pleurotoma n. sp.	×	....	....
Terebra sp. A	×	....	....
Terebra sp. B	×	×	....
Turritella n. sp.	×	....	....
ECHINODERMATA.			
Encope tenuis n. sp.	×	....	....
Cidaris sp.	×	....	....
Clypeaster bowersi Weaver	×	....	....
Clypeaster carrizoensis n. sp.	×	....	....
Clypeaster deserti n. sp.	×	....	....
Hipponoë californica n. sp.	×	....	....

Regarding the echinoids Kew[1] says that "*Clypeaster bowersi* Weaver resembles *Echinanthus* (*Clypeaster?*) *testudinarius* Gray, living in the Gulf of California," and that "The Recent *Hipponoë depressa* A. Agassiz found in the Gulf of California and on the west coast of Lower California is closely allied to *Hipponoë californica*."

Nomland[2] refers the coralliferous beds on Carrizo Creek to the Pliocene, and he says in a letter to me dated June 13, 1916:

In regard to the Pliocene age of the Carrizo Creek beds there is only very little evidence. Dr. Arnold correlated the Etchegoin[3] with the Carrizo Creek beds and thought both of Miocene age. His correlation was based almost entirely on *Pecten deserti* Conrad. Later we found, as shown by land vertebrates, that the Etchegoin formation and, as we thought, also the Carrizo Creek beds are of Pliocene age. I have recently collected from the Etchegoin a large number of specimens of the form called *Pecten deserti* by Arnold. I find, however, that this is undoubtedly different from the species occurring in the Carrizo Creek beds. The Pelecypoda and Gastropoda which have heretofore been specifically listed may be either Miocene or Pliocene.

In addition to the species and varieties listed in the accompanying table Nomland describes and figures a coral from Carrizo Creek under the name *Madripora solida*. I have not seen this species and am not sure as to its generic relations. I suppose "Madripora" is intended to be Madrepora, type species *Madrepora oculata* Linnæus = *Amphelia oculata* (Linnæus) Milne Edwards and Haime. I am confident that the species does not belong to Madrepora.

The specific affinities of the Carrizo Creek corals are discussed in detail after the descriptions in the systematic part of this paper. The Carrizo Creek species are so near species belonging to the same genera in the Pliocene Caloosahatchee marl of Florida and in the Pleistocene and living reefs of Florida and West Indies that it seems to me they can scarcely be so old as Miocene; lower Pliocene appears to be the maximum age which may be assigned to the fauna.

Corals from Carrizo Creek, Cal.

Name.	Most nearly related species in Florida or West Indies.[a]
Eusmilia carrizensis Vaughan, n. sp	Eusmilia fastigiata (Pallas), Pl, R.
Dichocœnia merriami (Vaughan)	Dichocœnia sp., P; D. stokesi Milne Edwards and Haime, Pl, R.
var. crassisepta Vaughan, n. var	
Siderastrea fairbanksi (Vaughan), typical	Solenastrea hyades (Dana) and S. bournoni Milne Edwards and Haime, P, Pl, R.
var. columnaris (Vaughan)	
var. normalis Vaughan, n. var	
var. minor Vaughan, n. var	
Mæandra bowersi Vaughan, n. sp	Mæandra labyrinthiformis (Linnæus), Pl, R.
Siderastrea mendenhalli Vaughan, n. sp	Siderastrea sp., P.
var. minor Vaughan, n. var	
Siderastrea californica Vaughan, n. sp	Siderastrea sp., P.
Porites carrizensis Vaughan, n. sp	Porites astreoides Lamarck, Pl, R.

[a] P, Pliocene; Pl, Pleistocene; R, Recent.

BEARING OF THE FAUNA OF CARRIZO CREEK ON A POSSIBLE POST-OLIGOCENE INTEROCEANIC CONNECTION.

That there was interoceanic connection across parts of Central America during upper Oligocene time and that this connection was terminated in Miocene time is generally admitted. The extinction of Pacific faunal elements in the Gulf of Mexico, the Caribbean Sea, and the western Atlantic Ocean has been discussed and summarized on page 366. Was there interoceanic connection during upper Miocene or Pliocene time after the sharp differentiation of the Caribbean and Mexican Gulf faunas from the Indo-Pacific faunas, thereby permitting interoceanic faunal migration? The discovery of a reef-coral fauna of purely Floridian and Caribbean facies at the head of the Gulf of California strongly suggests, if it is not positive proof, that the western Atlantic fauna extended from the Atlantic into the Pacific after the faunal differentiation had

[1] Kew, W. S. W., op. cit., pp. 50, 51.

[2] Nomland, J. O., Corals from the Cretaceous and Tertiary of California and Oregon: California Univ. Dept. Geology Bull., vol. 9, p. 60, 1916.

[3] Arnold, Ralph, Paleontology of the Coalinga district, Fresno and Kings counties, Cal.: U. S. Geol. Survey Bull. 396, p. 44, 1909.

taken place. It is well known that the living reef-coral fauna on the Pacific side of Central America is depauperate in comparison with that on the Atlantic side. Greater vigor may account for the dominance of the migrant fauna over the Pacific fauna, which was finally suppressed, or geologic or other ecologic conditions that are not yet understood may have excluded the Pacific fauna from the head of the Gulf of California, while they permitted the migration of the Atlantic fauna into that area.

That the suggested interoceanic connection existed can scarcely be doubted. To locate it, in the present state of meager knowledge of the areal and stratigraphic geology of Central America, is not possible. Perhaps it was across the Isthmus of Tehuantepec. The problem awaits future investigation.

CONCLUSIONS.

The foregoing discussion may be summarized as follows:

1. The Carrizo Creek reef-coral fauna is Atlantic, not Pacific, in its affinities.

2. During Eocene and Oligocene time there was connection between the Atlantic and Pacific oceans across Central America, and there was no sharp differentiation between the Atlantic and Pacific faunas.

3. Upper Oligocene (Apalachicolan) time was closed by diastrophic and other geologic events of profound importance, which separated the Atlantic from the Pacific Ocean by forming a land area extending from North to South America. During Miocene time sharp differentiation between the Atlantic and Pacific faunas took place, largely by the extinction of the Pacific elements in the Atlantic area.

4. The Pliocene coral fauna of Florida is purely Atlantic in its affinities, and since Pliocene time there has been only minor modification of the coral fauna in the western Atlantic, the Gulf of Mexico, and the Caribbean Sea.

5. The fauna of Carrizo Creek is related to Pliocene and post-Pliocene faunas of Florida and the West Indies and can scarcely be older than lower Pliocene.

6. Subsequent to the differentiation between the Atlantic and the Pacific faunas there was in upper Miocene or Pliocene time interoceanic connection, which permitted the Atlantic fauna to extend into the Gulf of California and up to its head, and conditions not yet understood excluded the Pacific fauna from the area.

7. The locus of the inferred interoceanic connection is not known. It was probably in the region of the Isthmus of Tehuantepec, or farther southeast.

SYSTEMATIC DISCUSSION OF THE FAUNA.

MADREPORARIA IMPERFORATA.

Family EUSMILIIDÆ Verrill.

Genus EUSMILIA Milne Edwards and Haime.

1848. Eusmilia Milne Edwards and Haime, Compt. Rend., vol. 27, p. 467.

Type species: *Madrepora fastigiata* Pallas.

Eusmilia carrizensis Vaughan, n. sp.

Plate XCV, figures 1, 1a.

Corallum cespitose, similar in growth form to *Eusmilia fastigiata*. Single branches as much as 13.5 by 15 millimeters in diameter. Costæ distinct but not very prominent, alternately larger and smaller, corresponding to the septa.

In a small corallite 8.5 millimeters in diameter there are about 16 septa which extend to the columella; alternating with these are shorter and much thinner septa. In places three smaller septa may be seen in a loculus between two large septa. In a space 5.5 millimeters long, measured on a chord, there are 7 septa.

Columella trabecular, well developed.

Locality: Barrett Canyon, Carrizo Creek, Imperial County, Cal.

Affinities: This species is about as close to *Eusmilia fastigiata* (Pallas), of the Floridian and Antillean region, as *Dichocœnia merriami* is to *D. stokesi*. The difference between the two is that *E. fastigiata* has more crowded septa, about ten in 5.5 millimeters, whereas *E. carrizensis* has seven in the same space. The growth form, the size of the branches, and the columellar character are the same in both.

Illustrations of *E. fastigiata* are given on Plate XCV, figures 2, 2a.

Genus DICHOCŒNIA Milne Edwards and Haime.

1848. Dichocœnia Milne Edwards and Haime, Compt. Rend., vol. 27, p. 469.
1857. Dichocœnia Milne Edwards and Haime, Histoire naturelle des coralliaires, vol. 2, p. 199 (type species figured, Pl. DI, figs. 10a, 10b).
Type species: *Astrea porcata* Lamarck, on authority of Milne Edwards and Haime.

It is my belief that *Madrepora porcata* Esper[1] is not this species, for Esper says: "Die Fläche ist ganz eben, und die Sterne ohne einen erhoheten Rand zu haben, eingesenkt." His figures suggest a coral similar to *Favia puteolina* (Dana) or *Favia danæ* Verrill. The *Dichocœnia porcata* of Milne Edwards and Haime differs from *D. stokesi* principally by the possession of an "épithèque extrêmement mince et peu distincte." It seems to me probable that their *D. porcata* and *D. stokesi* are the same species, especially as I have never seen a specimen of a living species of Dichocœnia from the Pacific or Indian Ocean, and none are reported by Studer, Stanley Gardiner, Bedot, Von Marenzeller, Gravier, or Matthai. According to the present available information, the genus is found living only in the western Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea. The *Dichocœnia uva* of Milne Edwards and Haime is based on Esper's *Madrepora uva*,[2] from the China Sea. This appears to be a species of Favia and is probably the same as *Favia speciosa* (Dana). From the description, it seems to me that *Dichocœnia stellaris* Milne Edwards and Haime is a varietal form of *D. stokesi*. A positive opinion can be based only upon a restudy of Milne Edwards and Haime's original specimens and types, but the suggestion is warranted that their *D. porcata*, *D. stokesi*, and *D. stellaris* all belong to the same species, and that both *Madrepora porcata* and *M. uva* of Esper belong to the genus Favia and not to Dichocœnia.

Dichocœnia merriami (Vaughan) Vaughan.

Plate XCIV, figures 1, 1a.

1900. *Favia merriami* Vaughan, U. S. Geol. Survey Mon. 39, p. 142, pl. 15, figs. 5, 5a–5c.
1906. *Favia merriami* Vaughan, in Arnold, Tertiary and Quaternary pectens of California: U. S. Geol. Survey Prof. Paper 47, p. 22.
1916. *Favia merriami* Nomland, California Univ. Dept. Geology Bull., vol. 9, p. 60.

[1] Esper, E. J. C., Fortsetzungen der Pflanzenthiere, pl. 71, 1795.
[2] Idem, pl. 43.

The original description of this species is as follows:

Corallum subplane or rounded above, massive. The species is based on three broken specimens, nearly of a size. * * * The condition of preservation of the material is, as is unfortunately too often the case with the fossil species, not satisfactory. The calices are elliptical. The following gives measurements of several:

	1	2	3	4
	Mm.	*Mm.*	*Mm.*	*Mm.*
Greater diameter of calice	6.5	6.5	5.5	5.5
Lesser diameter of calice	4.5	2.5	4.5	4.5

Some calices are almost circular, with a diameter of 4.5 millimeters. The calices are from 2 to 3 millimeters apart. The walls between the corallites are thick (2 to 3 millimeters) and usually compact; are evidently formed of fused costæ; correspondingly, sometimes the costæ can in the sections be traced some distance across the area between the corallites. On the upper surface of the corallum costæ correspond to all septa and extend from one calice to the next. They are low, sometimes flattened above or slightly acute, minutely granulated, straight or somewhat flexuous. Septa, in calice No. 1 of the above table, about 33 in number. The number for the fully grown calices seems to vary between 30 and 36; younger calices may have only 24. The various cycles are not distinctly indicated. There is usually a fairly regular alternation in size of the septa, the larger ones reaching the columella. They are thick, thicker at the wall, and have paliform thickenings on their inner ends. Faces granulate. Dissepiments very well developed, thin, 1.5 to 2.5 millimeters apart in the longitudinal section of the corallites. The character of the septal margins is not shown by the material at hand. The calicular fossæ are extremely shallow or are almost superficial. The columella is false, large, well developed.

The large suite of specimens collected by Mendenhall and Bowers makes a fuller description of the species possible.

The corallum is of massive growth form, upper surface regularly domed or undulate. The following are the dimensions of four specimens:

Dimensions of Dichocœnia merriami, in millimeters.

	Length.	Breadth.	Height.	Length of calices.	Width of calices.	Width of intercorallite walls.
1	133	107	76	6–17	3.5–6	1–4
2[a]	151	111	97	5.5–13	3.5–6.5	1–3
3	147	116	85	5.5–10	4–5.5	1–5
4	147	121	83	4.5–12.5	3–7	1–4

[a] Upper surface with humps.

The size of the calices is given in the table. The shortest calices have been recently cut off by fission from the parent corallite and are subcircular or elliptical in form. In the longest calices there are usually three centers which have not been isolated by complete fission. The distance apart ranges from the thickness of a dividing septum to about 5 millimeters. The least width of the corallite wall as given in the table is for calices which are completely separated and have developed intercorallite walls.

The calicular edges are somewhat elevated, the outer surface of the corallites sloping or falling almost perpendicularly to the bottom of the intercorallite depressions. The maximum amount of exsertness on these specimens is about 1 millimeter. Costæ correspond to the septa but usually are not notably prominent.

The septa and columella are better shown in the specimen represented by Plate XCIV, figures 1, 1a, described below.

Corallum subhemispherical, 57 by 67 millimeters in diameter and 39 millimeters tall. Corallites project as much as 2.5 millimeters; distance between calicular margins from 1 to 3 millimeters; free limbs with distinct subequal or slightly alternating costæ that correspond to all septa. Length of calices from 5 to 13.5 millimeters; width from 3 to 6.5 millimeters. Septa in a young corallite 4 millimeters in diameter about 18, of which 8 reach the columella; in a corallite 5.5 by 8.5 millimeters in diameter, there are 43 septa, of which 12 are appreciably larger than the others and reach the columella, and 8 others are nearly as large; alternating with the 20 larger septa are smaller septa, and there are a few rudimentaries. Another corallite 10.5 millimeters long has 42 septa, of which about half reach the columella, and there is an equal number of smaller septa. In places three sizes of septa are recognizable, and here and there are septal groups of threes. Septal margins apparently entire; paliform lobes commonly present. Septal faces granulate.

Columella trabecular, well developed; in some elongate calices an axial lamella is present, but this is derived from a septum.

Locality: Barrett Canyon, Carrizo Creek, Imperial County, Cal.

Affinities: This species is very close to *Dichocœnia stokesi* Milne Edwards and Haime, which is found on the living reefs in the Bahamas, the West Indies, and Florida, and occurs fossil in Santo Domingo, where it has been known as *Barysmilia intermedia* and *Dichocœnia tuberosa*, both proposed by Duncan.[1] A closely related species is found in the Pliocene Caloosahatchee marl of Florida, but descriptions and figures of it have not been published. There are in the United States National Museum large suites of *D. stokesi*. In growth form, general aspect, the size and distribution of the calices, and the character of its costæ it is like *D. merriami*, but the columella of *D. stokesi* seems to be less well developed, and a calice 4.5 by 7 millimeters in diameter has 42 septa, one 5 millimeters in diameter has 34 septa, and one 4 millimeters in diameter has 24 septa. Therefore *D. stokesi* seems to have a weaker columella and somewhat more numerous septa than *D. merriami*, but the differences are so slight that the California specimens should perhaps be referred to the same species as the one to which the Floridian and West Indian specimens belong. To facilitate comparison of the two species, figures of *D. stokesi* are given in Plate XCIV, figures 2, 2a.

Dichocœnia merriami var. crassisepta Vaughan, n. var.

Plate XCIV, figures 3, 3a.

This variant has thick, strongly exsert principal septa with corresponding strong costæ and thin intermediate septa with corresponding thin costæ. The differential characters are shown in the figures.

Locality: Barrett Canyon, Carrizo Creek, Imperial County, Cal.

Family ORBICELLIDÆ Vaughan.

Genus SOLENASTREA Milne Edwards and Haime.

1848. Solenastrea Milne Edwards and Haime, Compt. Rend., vol. 27, p. 494.

1850. Solenastrea Milne Edwards and Haime, British fossil corals, Introduction, p. xl.

Type species: *Astrea turonensis* Michelin.

The following is the characterization of the genus published by Milne Edwards and Haime in 1850:

Corallum forming in general a convex mass, of a light and cellular structure. Gemmation extra calicular. Co-

[1] London Geol. Soc. Quart. Jour., vol. 19, pp. 431, 432, 1863.

rallites long, slender, and united by an exothecal structure, and not by costæ, which do not meet and are often rudimentary. Calices circular, with an exsert margin. Columella spongy, and in general small. Septa very thin; their margin denticulated. Dissepiments simple, numerous, and closely set.

Solenastrea and Cyphastrea were united by Duncan under the former name, the latter being reduced to subgeneric rank,[1] and characterized as follows: "The generic characters are as in Solenastrea, but the septa are cribriform."

Leptastrea, Solenastrea, Cyphastrea, and Orbicella are closely related genera. The following paragraphs indicate what seem to me to be the differential characters.

Leptastrea Milne Edwards and Haime (type species, *L. roissyana* Milne Edwards and Haime), septa imperforate, corallites usually not joined by costæ, intercorallite tissue compact, its surface more or less granulate but not spinulose.

Solenastrea Milne Edwards and Haime (type species, *Astrea turonensis* Michelin), similar to Leptastrea, except that the corallites are separated by highly vesicular exotheca, unless crowded, when they may be separated by simple walls.

Cyphastrea Milne Edwards and Haime (type species, *Astrea microphthalma* Lamarck), similar to Solenastrea, except that the inner parts of many septa are cribriform, and the surface of the intercorallite tissue is spinulose.

Orbicella Dana (type species, *Madrepora annularis* Ellis and Solander), similar to Cyphastrea, except that the costæ are strongly developed and extend from one corallite to another.

I have been perplexed and have vacillated in my treatment of Solenastrea, sometimes referring it to the synonymy of Cyphastrea, sometimes to that of Orbicella. I am now retaining it as a valid genus for the following reasons: There is a group of species which is represented in the Recent and fossil faunas of Florida and the West Indies, and which shows constant characters. The group is well represented in the Tampa upper Oligocene, in the Caloosahatchee Pliocene, and in both the Pleistocene and living faunas. Except where the corallites are greatly crowded, they are separated by highly vesicular intercorallite tissue, the upper surface of which is granulate and more or less costate but not spinulose. The costæ may or may not extend from one corallite to the next; if the corallites are close together they may meet, but if the corallites are distant they usually do not meet. The costæ where well developed have not along their summits dentations, as in Orbicella, nor small sharp spinules, as in Cyphastrea. Because of the constant differences between this group of species and other genera, and of the constant similarity within the group, apparently it should have generic recognition.

[1] Linnean Soc. London Jour., vol. 18, p. 107, 1884.

Unfortunately no specimens of the type species of Solenastrea are available to me for study; but to judge from Michelin's very good figures and from the description of Milne Edwards and Haime the foregoing statement applies to the characters of the genotype.

There are two species in the living West Indian fauna, both of which also occur in the Caloosahatchee Pliocene. One is *Solenastrea hyades* (Dana) (see Pl. XCVIII, all figures), which appears to be a synonym of *Madrepora pleiades* Ellis and Solander, and *Solenastrea bournoni* Milne-Edwards and Haime (see Pls. XCIX and C, all figures), of which the following species of Duchassaing and Michelotti are synonyms: *Heliastræa abdita*, *Leptastræa caribæa*, *Cyphastræa carpinetti*, *Solenastræa micans*, and *Solenastræa ellisi*. In *S. hyades* the members of the third cycle of septa fuse to the sides of the secondaries; in *S. bournoni* the inner ends of the tertiaries are free.

Solenastrea fairbanksi (Vaughan) Vaughan, typical.

Plate XCV, figures 3, 3a.

1900. *Stephanocœnia fairbanksi* Vaughan, U. S. Geol. Survey Mon. 39, p. 151, pl. 17, figs. 11, 11a.

1906. *Plesiastrea californica* (nomen nudum) and *Stephanocœnia fairbanksi* Vaughan, in Arnold, Tertiary and Quaternary pectens of California: U. S. Geol. Survey Prof. Paper 47, p. 22.

1916. *Stephanocœnia fairbanksi* Nomland, California Univ. Dept. Geology Bull., vol. 9, p. 60.

The original description of this species is in part as follows:

Form of corallum explanate or columnar. The specimens possessing the explanate method of growth may be considered the typical form; those with the columnar method of growth, *S. fairbanksi* var. *columnaris* var. nov. * * * The corallites are polygonal in form, usually hexagonal, and are joined directly by their walls or by very short costæ. The greater diameter of the corallites is very constantly 3.5 millimeters. Some corallites may be smaller and some slightly larger, but 3.5 millimeters is the usual diameter. The walls between two corallites on an unweathered surface or in a section are stout and usually solid; they are almost a millimeter thick. They are clearly pseudothecal. In places the corallites may be joined by very short costæ; then open vertical spaces may exist between the costæ. None of the specimens shows the upper edge of the wall in its original condition; therefore its ornamentation can not be described. The septa are in three complete cycles; the members of the first and second cycle fuse to the columella; those of the third cycle fuse to the sides of those of the second (?). (There is no way of differentiating the first from the second cycle.) They are thicker at the wall; their faces granulate. The character of the septal margins could not be studied. In the best-preserved calices there appear to be pali before both the first and second cycles of septa. In the thin section both of these cycles of septa show thickenings on and near their inner ends corresponding in position to the apparent lobes on the septa. The calices are not preserved intact, but that 12 pali existed seems quite clear. Endotheca very well developed.

The original description needs modification in only one particular. The excellent suite of specimens obtained by Mendenhall and Bowers shows that the columella is trabecular and is not like that of the type species of Stephanocœnia (*Madrepora intersepta* Esper). The tertiary septa may or may not fuse to the sides of the secondaries; in the same calices some of the tertiaries are fused to the secondaries, and others have free inner margins.

As often happens when a new species is based on a single specimen, or only a few specimens, the type specimen of this species does not represent the usual character of the species. The type has an explanate mode of growth and crowded calices separated by narrow walls. Plate XCV, figure 3, represents a typical specimen, one-half natural size. It is a pulvinate mass, 185 millimeters in diameter, and 68 millimeters thick. Plate XCV, figure 3a, represents a group of calices, enlarged four times. Specimens such as this might be considered to represent a species distinct from those later described as the varieties *normalis* and *minor*, were not intergradation completely shown. Plate XCV, figures 4, 4a, gives two views of two calicular areas, each enlarged four times, on the same specimen, to show variation in the intercorallite walls. It appears that flattish colonies have crowded calices and that more or less hemispherical colonies have more distant calices.

Locality: Alverson Canyon, Carrizo Creek, Imperial County, Cal.

Solenastrea fairbanksi var. columnaris (Vaughan) Vaughan.

Plate XCVI, figures 1, 1a.

1900. *Stephanocœnia fairbanksi* var. *columnaris* Vaughan, U. S. Geol. Survey Mon. 39, p. 151, pl. 17, figs. 10, 10a.

1906. *Stephanocœnia fairbanksi* var. *columnaris* Vaughan, in Arnold, Tertiary and Quaternary pectens of California: U. S. Geol. Survey Prof. Paper 47, p. 22.

1916. *Stephanocœnia fairbanksi* var. *columnaris* Nomland, California Univ. Dept. Geology Bull., vol. 9, p. 60.

This variety differs from the typical form of the species in its columnar growth form and on the average its wider intercorallite areas. Both characters are shown in the figures.

Locality: Barrett Canyon, Carrizo Creek, Imperial County, Cal.

Solenastrea fairbanksi var. normalis Vaughan, n. var.

Plate XCVI, figures 2, 2a, 2b, 2c; Plate XCVII, figures 1, 1a.

Most of the specimens of this variety are more or less hemispherical in form, and some attain a height of over 320 millimeters. The calicular characters are similar to those of the type specimen, except that the calicular margins are free, are slightly elevated, and may be as much as 2 millimeters apart. The costæ are distinct just below the calicular margins and may or may not meet on the intercorallite areas.

The range in diameter of the calices is from 2.5 to 3.5 millimeters, and the usual diameter is about 3 millimeters. This variety is discriminated from variety *minor* solely by its somewhat larger calices.

Localities: Alverson and Barrett canyons, Carrizo Creek, Imperial County, Cal.

Solenastrea fairbanksi var. minor Vaughan, n. var.

Plate XCVII, figures 2, 2a, 2b, 2c.

This variety differs from var. *normalis* by its smaller calices, which range from 1.5 to 2 millimeters in diameter. The inner ends of the tertiary septa are usually but not invariably free.

Locality: Alverson Canyon, Carrizo Creek, Imperial County, Cal.

Affinities of Solenastrea fairbanksi.

The illustrations of *Solenastrea fairbanksi* (Pl. XCV, figs. 3, 3a, 4, 4a; Pl. XCVI, all figures; and Pl. XCVII, all figures) may be compared with those of *Solenastrea hyades* (Dana) (Pl. XCVIII, all figures), from the Pliocene Caloosahatchee marl of Florida, and with those of *Solenastrea bournoni* Milne Edwards and Haime (Pls. XCIX and C, all figures), which is now living in the West Indies and is a common species in the Caloosahatchee marl in Florida. Although these seem to be three well-marked species they are all closely related. The only species at present living in the Pacific which seems to me to belong systematically near this group of species is the coral from Wake Island to which Dana applied the name *Astræa* (*Orbicella*) *pleiades* and which was subsequently referred to Solenastrea by Verrill. (Dana's original specimen is No. 56, U. S. National Museum.) The Carrizo Creek specimens seem to me more closely related to the West Indian and Floridian specimens than to the form from Wake Island.

Family FAVIIDÆ Gregory.

Genus MÆANDRA Oken.

1815. Mæandra Oken, Lehrbuch der Naturgeschichte, Theil 3, Abt. 1, p. 70.

1902. Mæandra Verrill, Connecticut Acad. Arts and Sci. Trans., vol. 11, p. 66.

Type species: *Madrepora labyrinthiformis* Linnæus.

Mæandra bowersi Vaughan, n. sp.

Plate CI, figures 1, 1a.

1906. *Diploria bowersi* (nomen nudum) Vaughan, in Arnold, Quaternary pectens of California: U. S. Geol. Survey Prof. Paper 47, p. 22.

Corallum massive, subhemispherical. Type is a piece of a specimen whose diameter is about 70 millimeters; thickness about 37 millimeters.

Valleys relatively long and sinuous, 27 millimeters a common length; one exceeds 40 millimeters. A few circumscribed calices; one of these is about 6.5 millimeters in diameter. Width of valleys from 3.75 to 5.5 millimeters; usually about 4 millimeters; depth about 2 millimeters. Interserial colline with a shallow median depression; width of colline from 1.75 to 3.5 millimeters, usually 2.5 to 3 millimeters. Costæ well developed, correspond to all septa, distant, edges acute.

Septa, about 8 large ones, which reach the columella, to 1 centimeter; intermediate rudimentary septa variable in development, present in some places, absent in others.

Columella false, trabecular, fairly well developed.

Locality: Carrizo Creek, Imperial County, Cal. Stephen Bowers, collector.

Affinities: This species resembles *Mæandra* ("*Diploria*") *labyrinthiformis*, of Florida and the Antilles, but as the latter has about 12 principal septa to the centimeter, the two species can readily be distinguished. Plate CI, figure 2, presents a view of the valleys and collines of *M. labyrinthiformis*, twice natural size. The only known living species of Mæandra closely related to *M. bowersi* are in the West Indies, none at all being known in the modern Indo-Pacific faunas.

MADREPORARIA FUNGIDA.

Family AGARICIIDÆ Verrill.

Genus SIDERASTREA De Blainville.

1830. Siderastrea De Blainville, Dictionnaire des sciences naturelles, vol. 60, p. 75.

Type species: *Madrepora galaxea* Ellis and Solander, 1786 = *Madrepora radians* Pallas, 1766.

Siderastrea mendenhalli Vaughan, n. sp.

Plate CI, figures 3, 3a, 4.

The corallum is massive in form and has a flattish, rounded, or undulate upper surface. Some colonies attained a large size, as one specimen, not here described in detail, is 425 millimeters tall and over 440 millimeters in diameter on its upper surface.

Calices regularly polygonal or usually more or less deformed; diameter from 4 to 7 millimeters in those regularly polygonal; greater diameter of deformed calices as much as 7 millimeters; shorter diameter, from about 2.5 to 4 millimeters. The calicular cavities are rather shallow, the septal margins sloping gently from the narrow intercorallite wall to the bottom of the fossa.

Septa rather thin, crowded, usually in four complete cycles, the higher cycles grouped around the secondaries and tertiaries, as is usual in the genus. In many small calices the fourth cycle is incomplete in some systems; in large calices there are many members of the fifth cycle. Septal dentations rather fine, 13 or more on the large septa; about 15 dentations were counted on a septum 2 millimeters long. Synapticulæ highly developed, extending more than halfway from the wall to the columella; as many as 10 were counted between the wall and the columella in one interseptal loculus.

Columella rather small, false; upper surface finely papillate.

Localities: Alverson and Barrett canyons, Carrizo Creek, Imperial County, Cal.

Affinities: This species belongs to the same group as *Siderastrea siderea* (Ellis and Solander), which is one of the common corals on the living reefs of Florida and the West Indies, but *S. siderea* has deeper, rather funnel-shaped calices. *S. mendenhalli* is close to a species found in the Caloosahatchee Pliocene of Florida but not yet described in print.

Siderastrea mendenhalli var. minor Vaughan, n. var.

Plate CII, figure 1.

This variant is separated from the typical examples of the species by the smaller average size of its calices. There is intergradation, as the largest calices of the variant are 4 millimeters in diameter, but most of them are 3 millimeters or less in diameter. The fourth cycle of septa is usually incomplete in some of the systems.

Locality: Barrett Canyon, Carrizo Creek, Imperial County, Cal.

Siderastrea californica Vaughan, n. sp.

Plate CII, figures 2, 2a, 3, 4.

1906. *Siderastrea californica* (nomen nudum) Vaughan, in Arnold, Tertiary and Quaternary pectens of California: U. S. Geol. Survey Prof. Paper 47, p. 22.

Corallum of massive growth form; upper surface flattish or rounded. The largest specimen is 75 by 93 millimeters in diameter, and 105 millimeters tall.

Calices polygonal, not greatly deformed. Diameter of a large, fully grown one 4.5 millimeters; usual diameter of adult calices 4 millimeters; young calices 2.5 millimeters or less in diameter. Walls rather thick. Calicular cavities shallow, or superficial.

Septa relatively thick, especially the six primaries and either two or four secondaries. There are three complete cycles, and in many specimens the fourth cycle is complete in four of the six systems but not developed in two systems, one on each side of a primary. The septal trabeculæ are coarse and produce about 10 dentations on a primary septum. As there are fewer septal trabeculæ there are correspondingly fewer and coarser synapticulæ than in *S. mendenhalli*.

Columella false, papillary; becomes secondarily compacted so that it projects as a stout style in weathered calices.

Localities: Carrizo Creek (type, Stephen Bowers collector); Barrett Canyon, Carrizo Creek, Imperial County, Cal.

Affinities: This species can be readily distinguished from *S. mendenhalli*, if the material is well preserved, by its fewer, thicker, and more coarsely dentate septa. It is very close to an undescribed species from the Caloosahatchee Pliocene and is near *S. radians* (Pallas), which is widely distributed in the Pleistocene and Recent reef areas of the western Atlantic Ocean and the Caribbean Sea. Both *Siderastrea mendenhalli* and *S. californica* are represented by closely related, very similar, parallel species in the Pliocene Caloosahatchee marl of Florida. The septa of one of the Florida species are composed of small trabeculæ, which produce finely dentate septal margins and crowded, small synapticulæ, as in *S. mendenhalli*. The septa of the other species are composed of relatively coarse trabeculæ, and therefore the septal dentations are coarse and the synapticulæ are large, as in *S. californica*. Living species of Siderastrea occur in the Philippine Islands, the Indian Ocean, and the Red Sea, but the closest relatives of the Carrizo Creek species are in the Caloosahatchee Pliocene of Florida.

MADREPORARIA PERFORATA.

Family PORITIDÆ Dana.

Genus PORITES Link.

1807. Porites Link, Beschreibungen der Naturaliens Sammlungen, Rostock, p. 162.
Type species: *Madrepora porites* Pallas.

Porites carrizensis Vaughan, n. sp.

Plate CII, figures 5, 5a, 5b, 6, 6a.

Corallum of nodular or subhemispherical form with small gibbosities on its surface. The holotype is 62.5 by 71 millimeters in diameter and 49 millimeters thick; upper surface flattish.

Calices polygonal, small, 1.4 to 1.7 millimeters in diameter; excavated, but only moderately deep. Separating wall interrupted, zigzag, with coarse mural denticles. Its upper edge may be acute, or in places where the outer margins of the septa are wide it may be flattish, with a slight development of intercorallite reticulum, which is as much as 1 millimeter across.

Septa rather thick, 12 in number, arranged according to the poritid scheme; there is a solitary directive, four lateral pairs, and a directive triplet. The inner ends of the triplet are more or less free; as a rule the laterals of the group do not pronouncedly bend toward the included directive, but in some calices they seem to join it. In places there are suggestions of trident formation. There is some indefiniteness in the lateral pairs.

In places the septa are narrow in their upper parts; usually they are relatively wide over the wall, where their upper margins are flattened, while their inner margins fall steeply to the bottom of the calicular fossa. Normally there is a single, somewhat detached, rather coarse septal granule between the wall and the palar ring. The specimens show a fairly well developed outer synapticular ring, and the palar synapticular ring is usually complete. There is no conspicuous thickening of the horizontal structures, the skeletal elements being predominantly radial in the septa, and concentric in the wall and in the synapticular rings within the calices.

Pali are fairly well developed but appear variable in number, from 4 to 6.

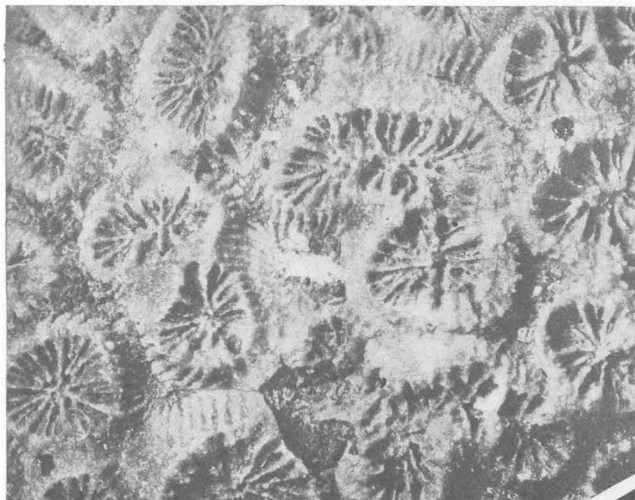
There is a weak columellar tubercle in some calices, but if it was present it has been broken in most of them.

Locality: Barrett Canyon, Carrizo Creek, Imperial County, Cal.

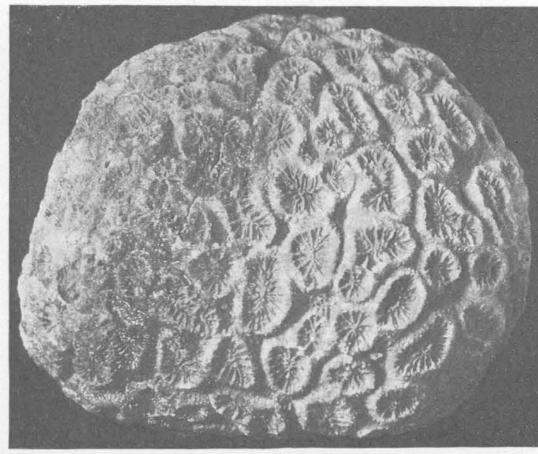
Affinities: This species has the same growth form, the same sized calices, the same mural characters, and the same kind of septal margins as *P. astreoides* Lamarck, of Florida and the West Indies. There is also a similar indefiniteness in the septal grouping of each species. The calices of *P. carrizensis* seem shallower and the pali better developed than in *P. astreoides*, but the two are remarkably alike.

PLATES XCIV-CII.

PLATE XCIV.



1a ×3



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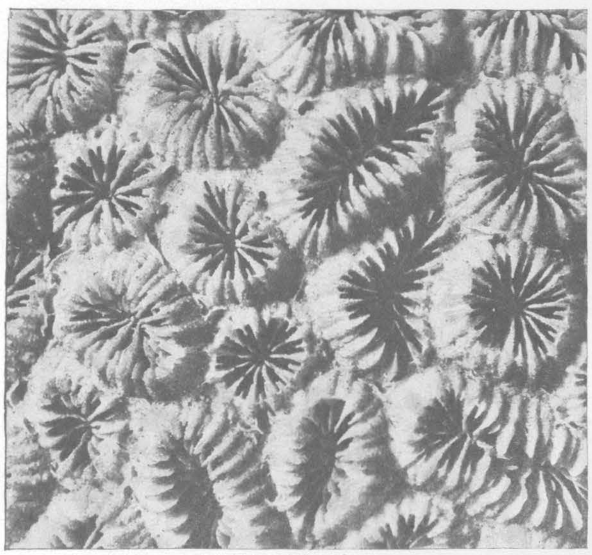
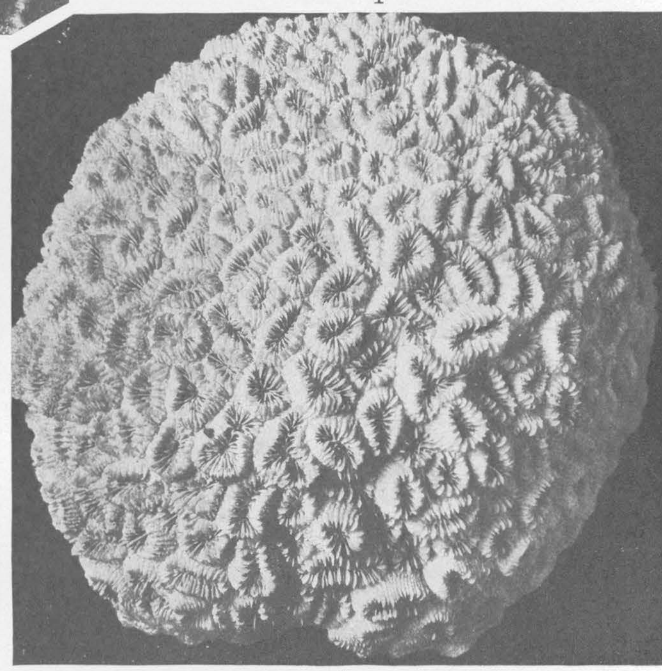


2a ×3



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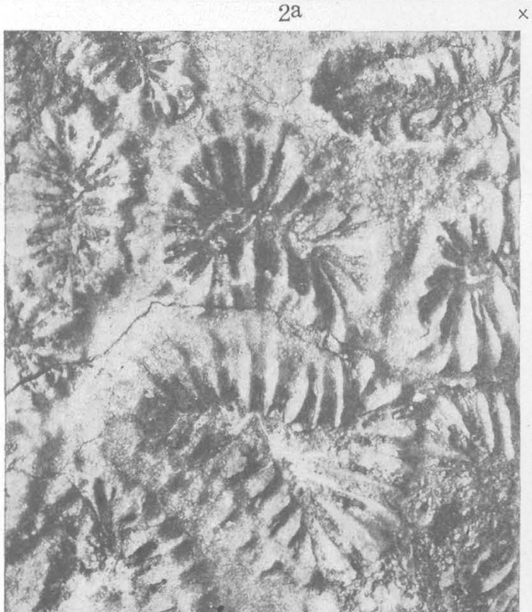
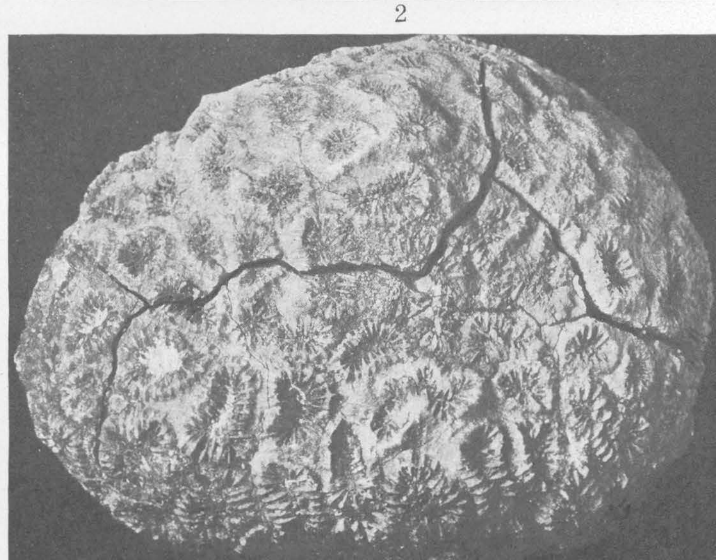


3a ×3



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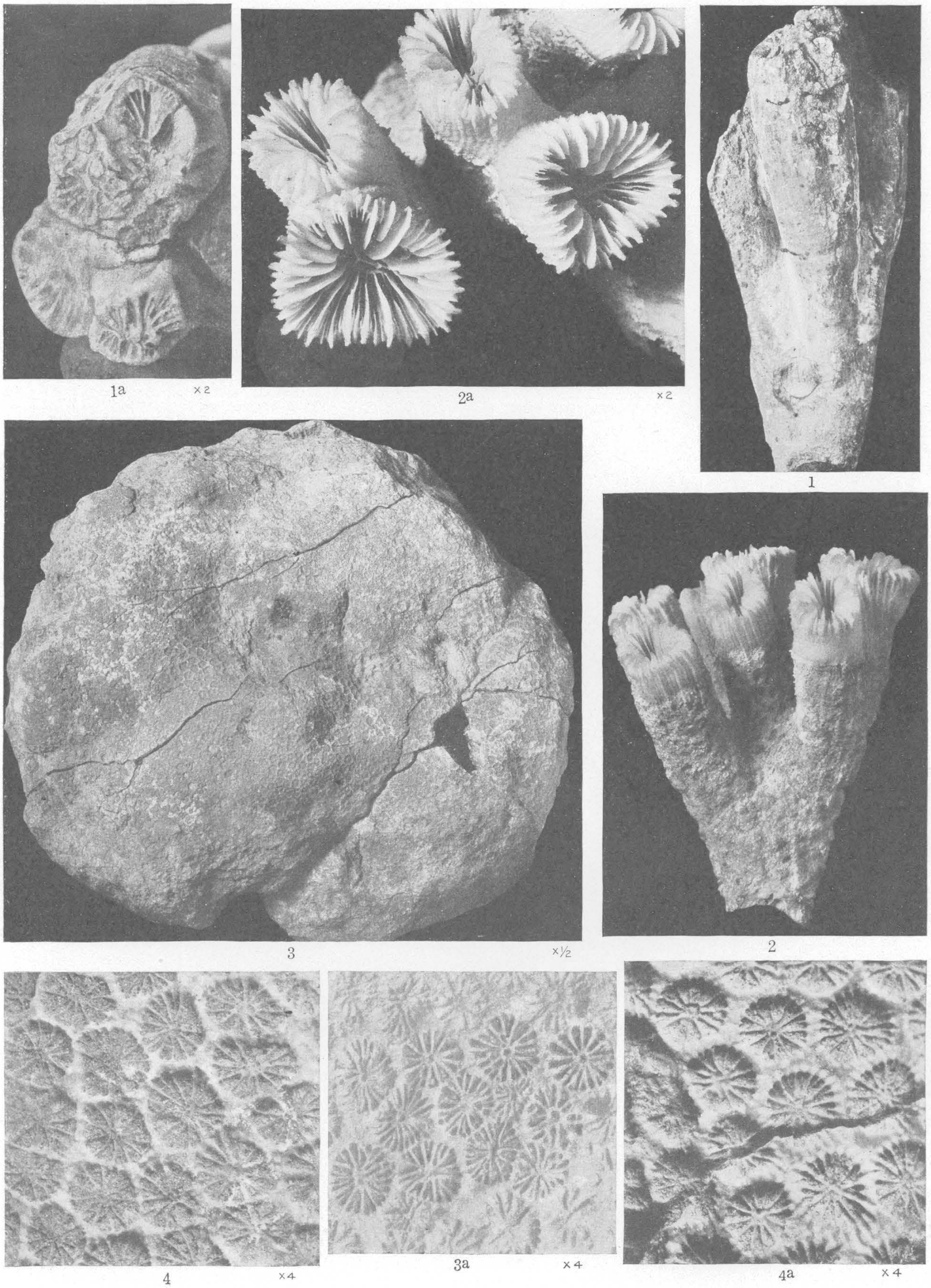
REEF CORALS.



REEF CORALS.

PLATE XCV.

		Page.

FIGURES 1, 1a. *Eusmilia carrizensis* Vaughan, n. sp., from Carrizo Creek, Cal.................................... 369

1. Corallum, natural size.

1a. Calicular ends of branches, × 2.

FIGURES 2, 2a. *Eusmilia fastigiata* (Pallas), the type species of the genus, from Cocoanut Point, east side of Andros Island, Bahamas.. 369

2. Corallum, natural size.

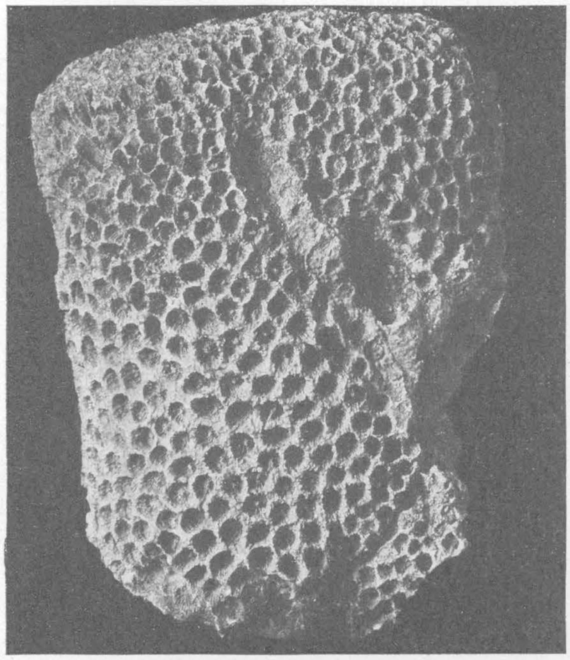
2a. Calices, × 2.

FIGURES 3, 3a. *Solenastrea fairbanksi* (Vaughan), typical, from Carrizo Creek, Cal.............................. 372

3, 3a. Two views of a specimen typical of the species; 3, upper surface of corallum, one-half natural size; 3a, calices, × 4.

FIGURES 4, 4a. Two views, each × 4, of the calices of a specimen whose calicular characters are between those exhibited by typical specimens of *Solenastrea fairbanksi* and those of var. *normalis*. (See Pl. XCVI, figs. 2–2c, and Pl. XCVII, figs. 1, 1a).. 373

PLATE XCVI.



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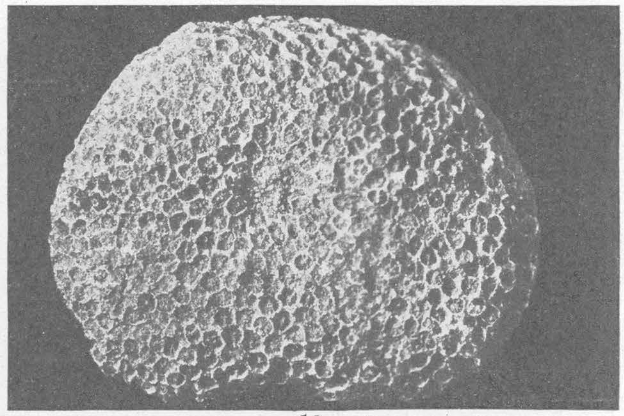
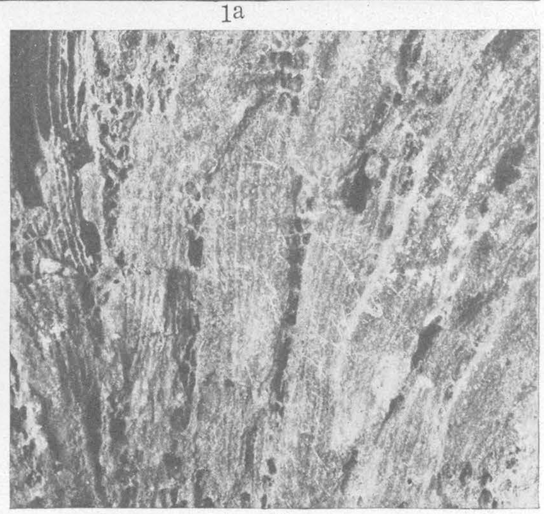
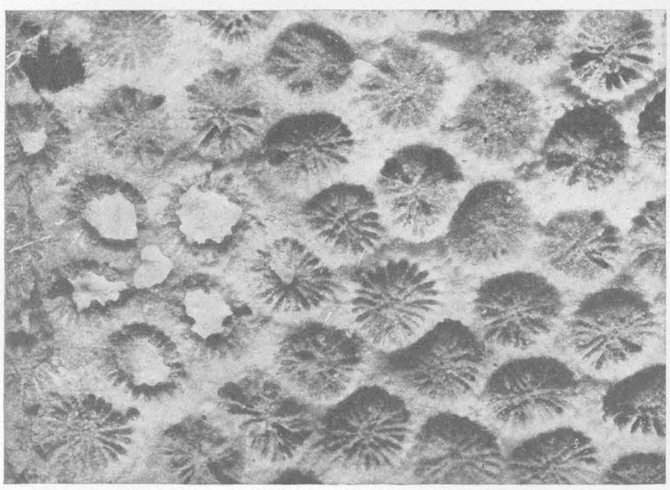


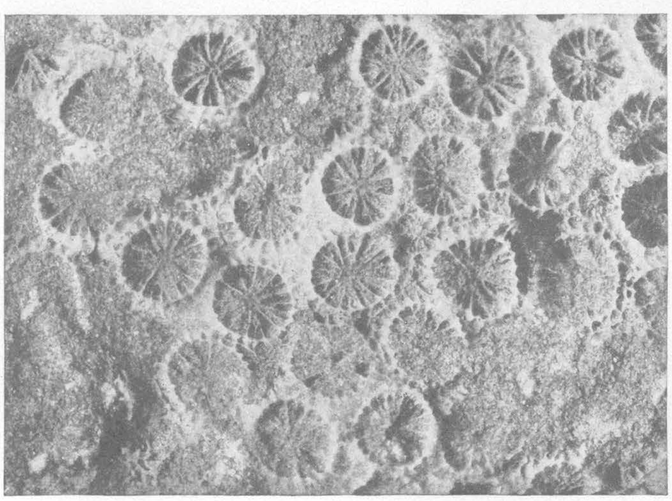
1a



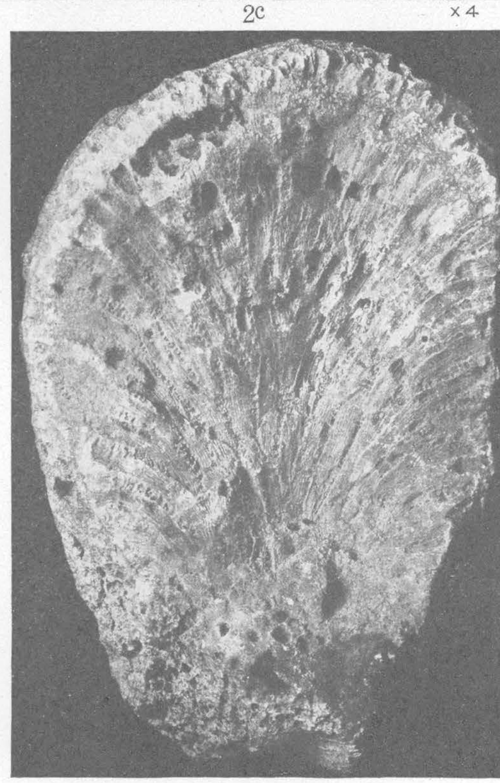
2c ×4



2a ×4



2b ×4



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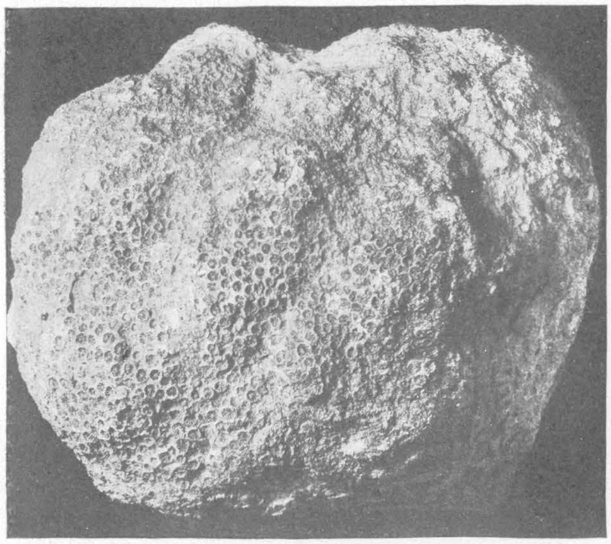
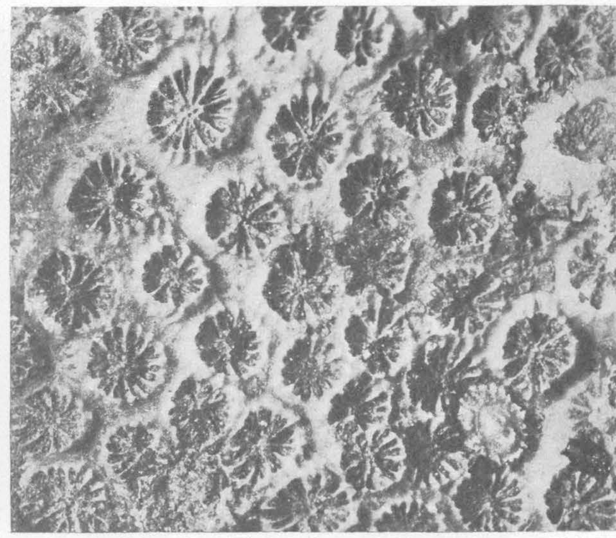
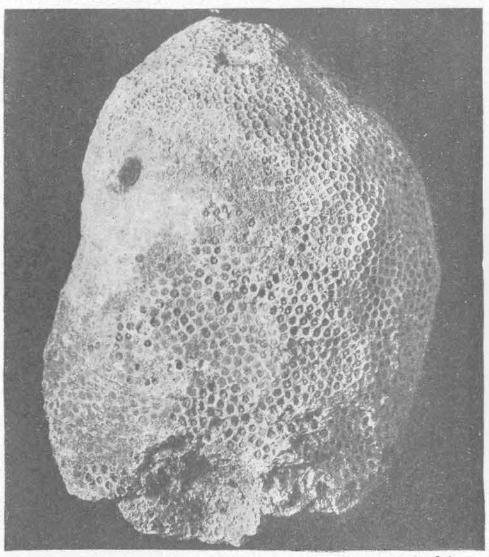
REEF CORALS.



1 ×½

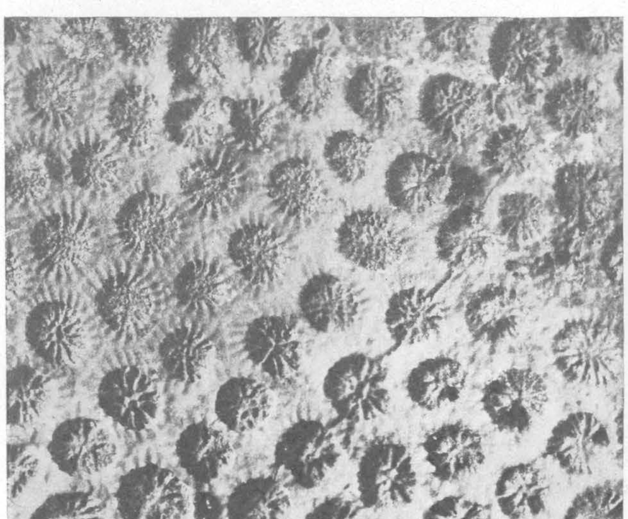


1a ×4

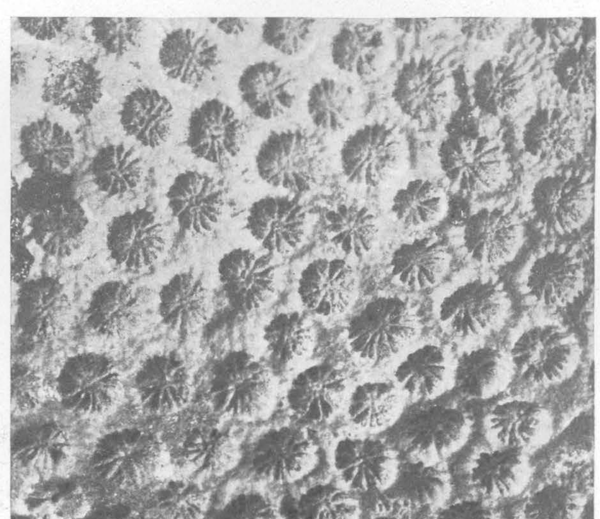


2 ×½

2a ×4



2b ×4



2c ×4

REEF CORALS.

PLATE XCVII.

Page.

FIGURES 1, 1a. *Solenastrea fairbanksi* var. *normalis* Vaughan, n. var., from Carrizo Creek, Cal. (See Pl. XCVI, figs. 2, 2a, 2b, 2c) 373

1. Corallum, one-half natural size.

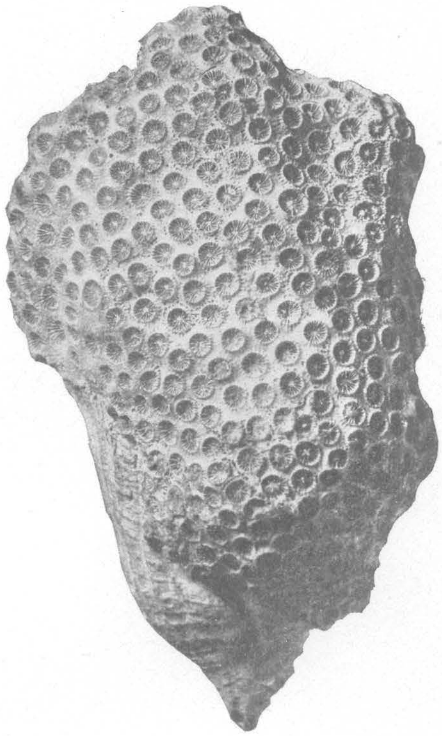
1a. Calices, × 4.

FIGURES 2, 2a, 2b, 2c. *Solenastrea fairbanksi* var. *minor* Vaughan, n. var., from Carrizo Creek, Cal 373

2. Corallum, one-half natural size.

2a, 2b, 2c. Calices, each × 4, from three areas.

PLATE XCVIII.



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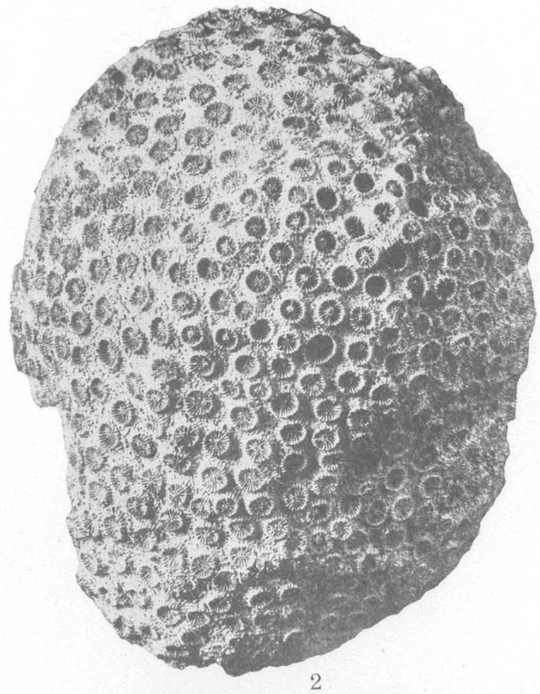

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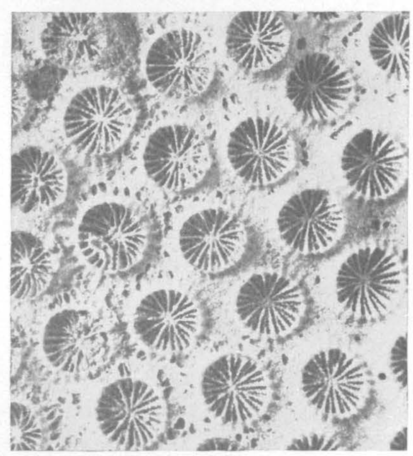
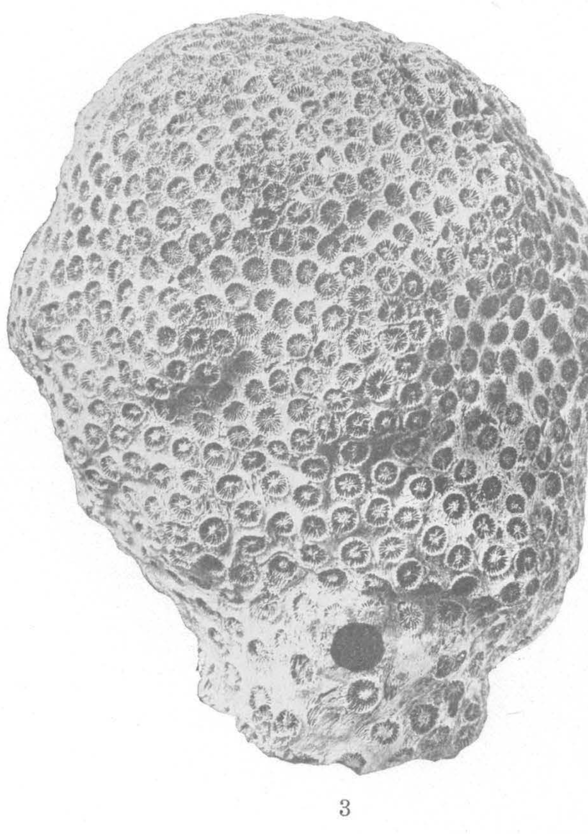


1a ×4



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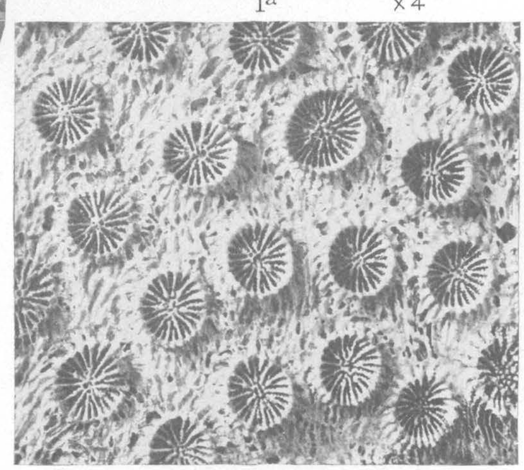
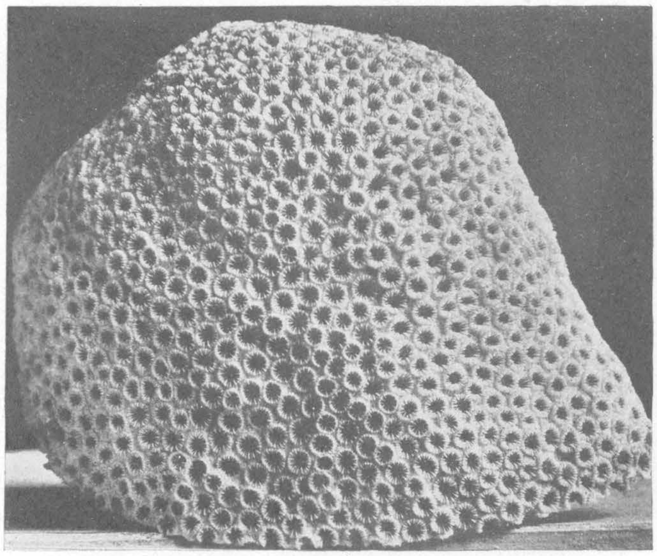


2a ×4

REEF CORALS.



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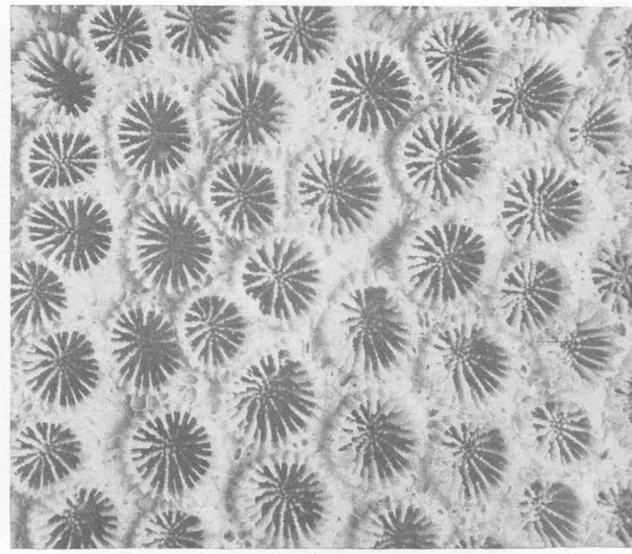
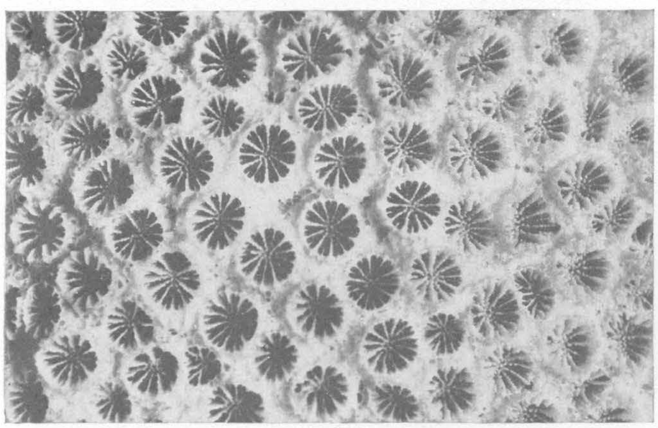
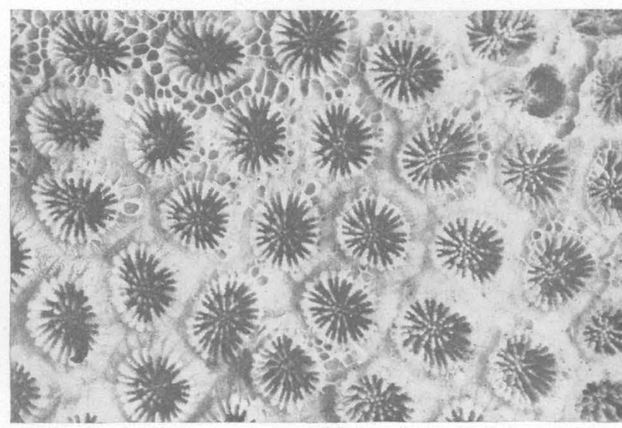


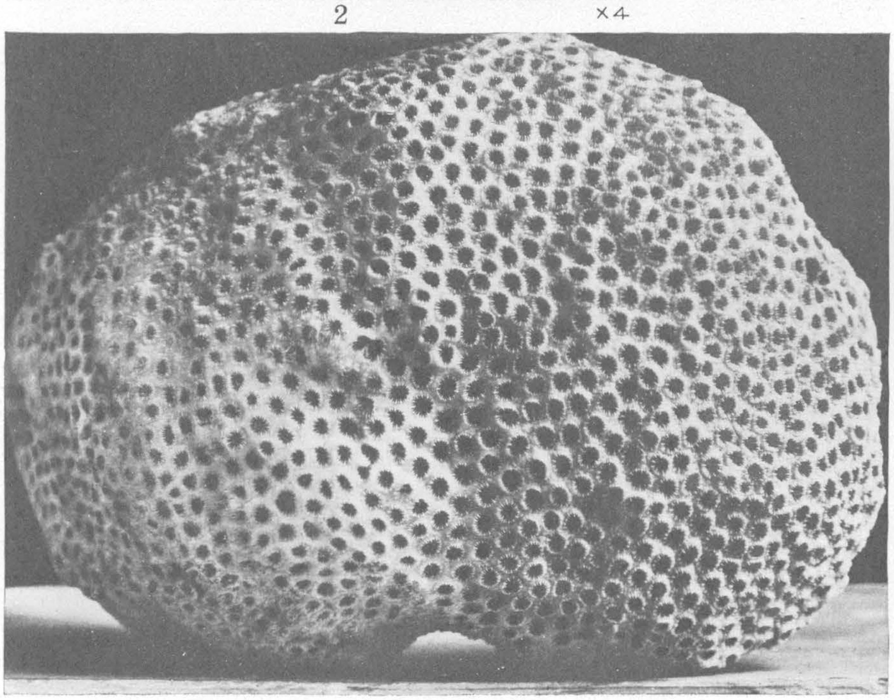
1^{a} ×4



2 ×4



3^{a} ×4



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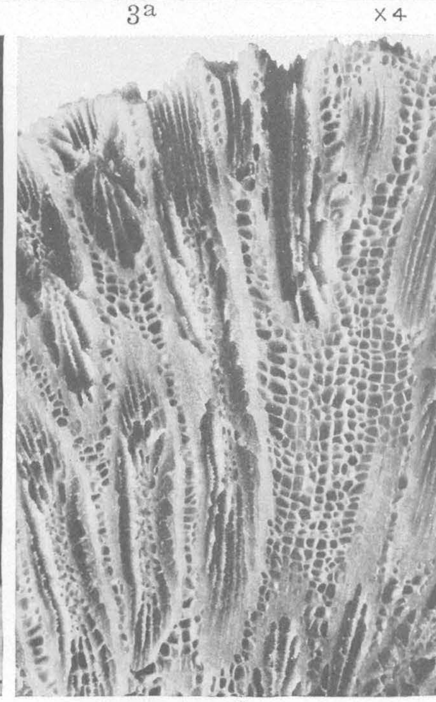


1^{b} ×4

REEF CORALS.

PLATE XCIX.

FIGURES 1, 1a, 1b, 2. Cotypes of *Solenastrea bournoni* in the Muséum d'histoire naturelle, Paris.

1. Corallum, natural size; 1a, calices, × 4; 1b, longitudinal section, × 4, of the same specimen.
2. Calices of a second specimen, × 4. (This specimen may be the true type.)

FIGURES 3, 3a. Specimen labeled *Cyphastrea oblita* Duchassaing and Michelotti, in the Muséum d'histoire naturelle, Paris.

3. Corallum, natural size.

3a. Calices, × 4.

The photographic negatives on which the figures in this plate are based were kindly supplied by Dr. Charles Gravier, of the Muséum d'histoire naturelle, Paris.

PLATE C.

Page.

Solenastrea bournoni Milne Edwards and Haime 374

FIGURE 1. Calices of a specimen from the Pliocene Caloosahatchee marl of Florida, × 4.

FIGURES 2, 2a. Two views of the same specimen, from the Caloosahatchee marl.

2. Transverse section of corallites, × 4.

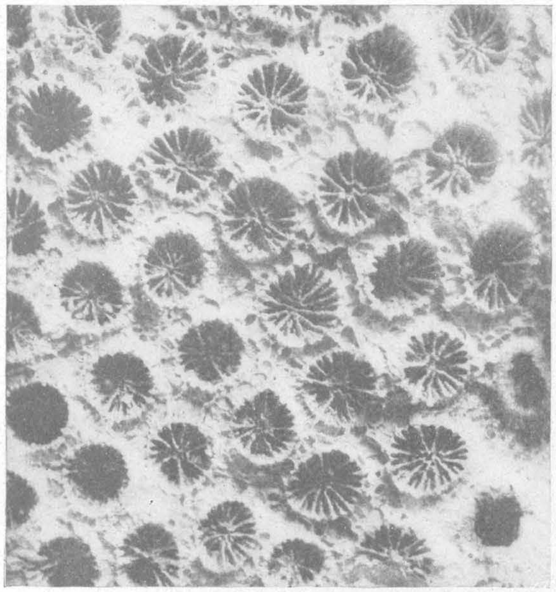
2a. Longitudinal section of corallites, × 4.

FIGURES 3, 3a, 3b. Three views of a part of Duncan's type of *Plesiastrea globosa* (presented to the U. S. National Museum by the Geological Society of London), from "silt of the plain, Santo Domingo."

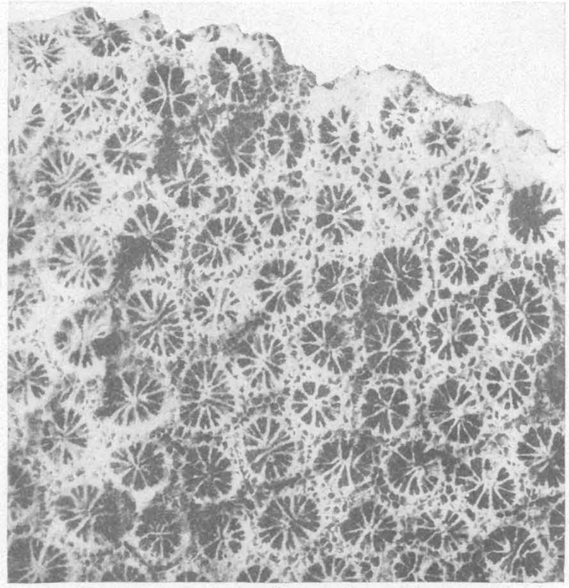
3. Corallum, natural size.

3a. Calices, × 4.

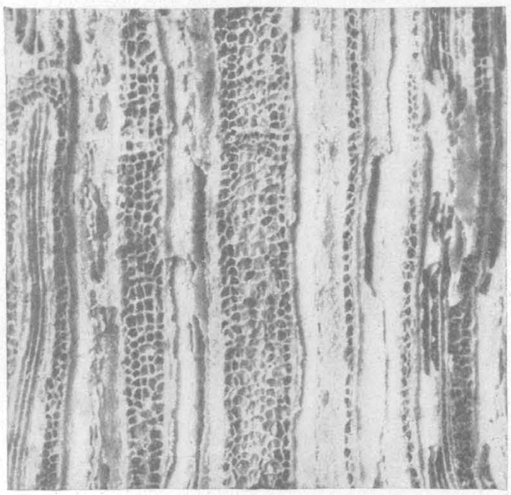
3b. Longitudinal section, × 4.



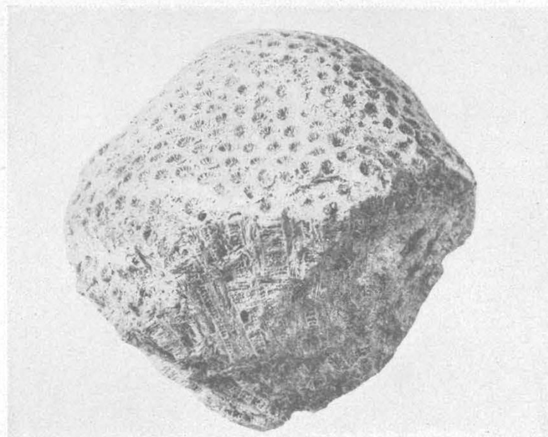
1 ×4



2 ×4



2a ×4



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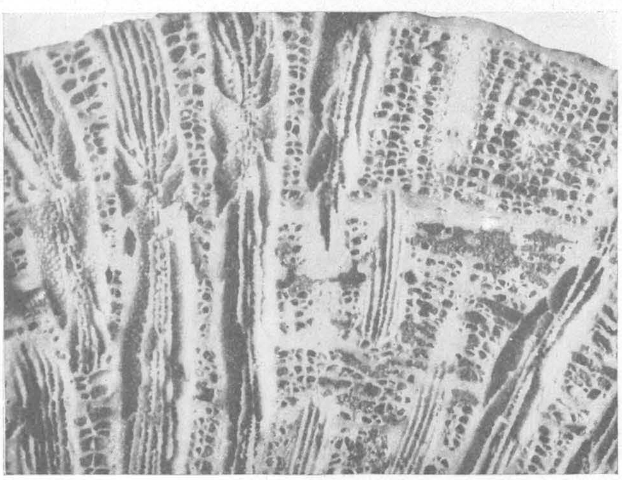
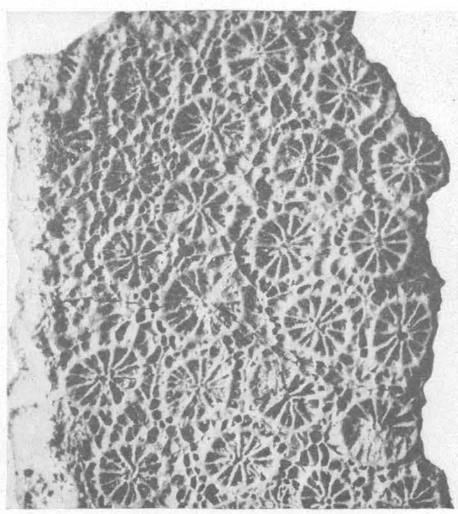
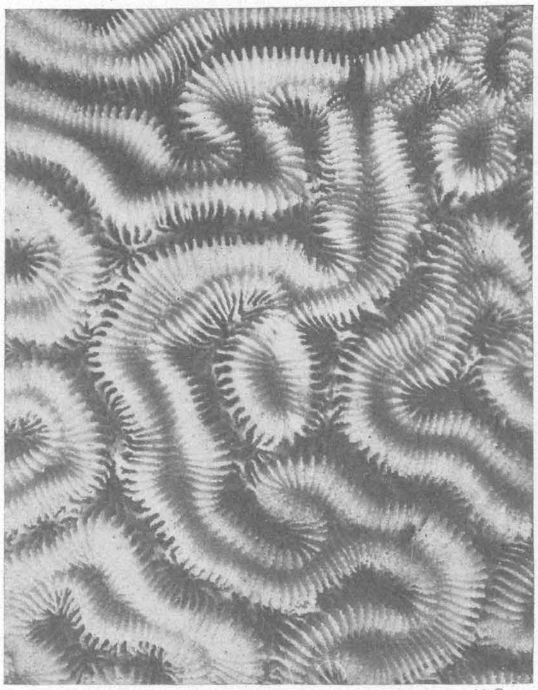


3b ×4

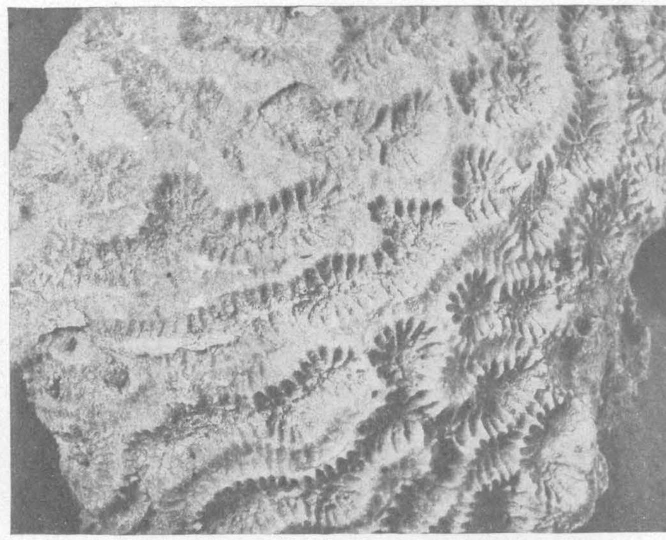


3a ×4

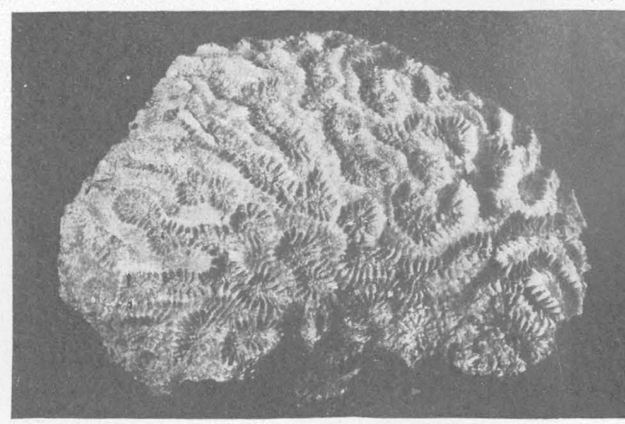
REEF CORALS.



2 ×2



1a ×2



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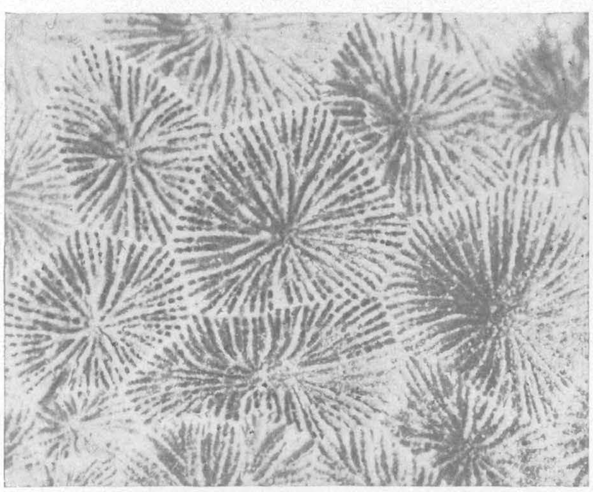
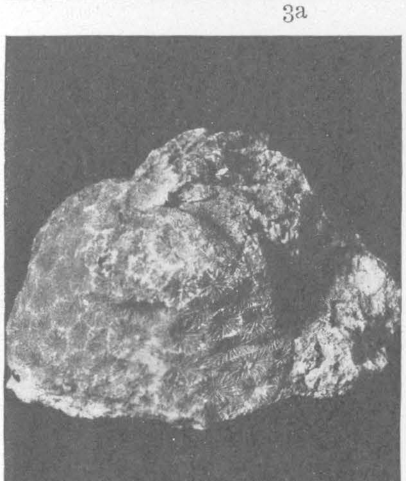


3a ×6



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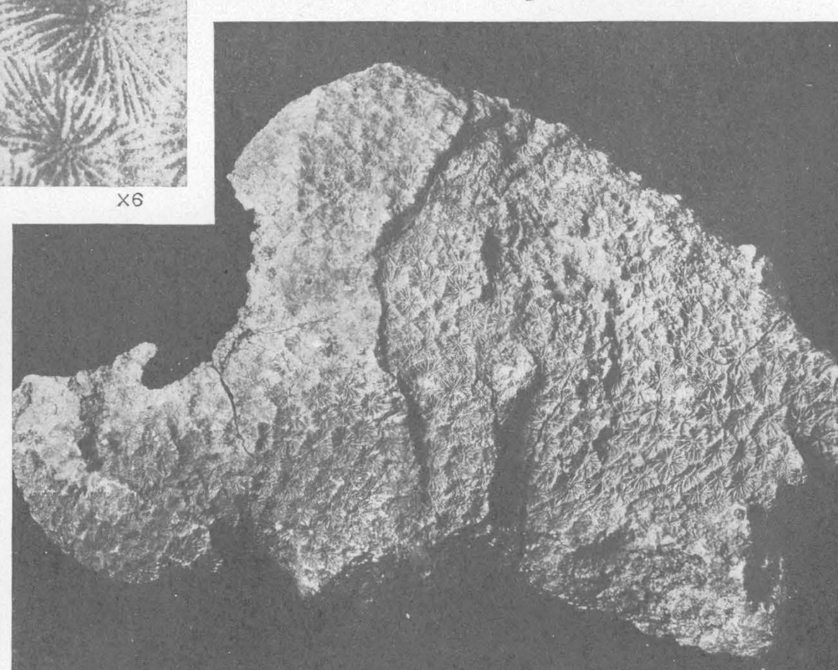


4

REEF CORALS.

PLATE CI.

PLATE CII.

	Page.
FIGURE 1. *Siderastrea mendenhalli* var. *minor* Vaughan, n. var., from Carrizo Creek, Cal. Calices, × 4	375
FIGURES 2, 2a, 3, 4. *Siderastrea californica* Vaughan, n. sp., from Carrizo Creek, Cal.	375

2, 2a. Two views of the holotype. 2, Upper surface of the corallum, natural size; 2a, calices, × 6.

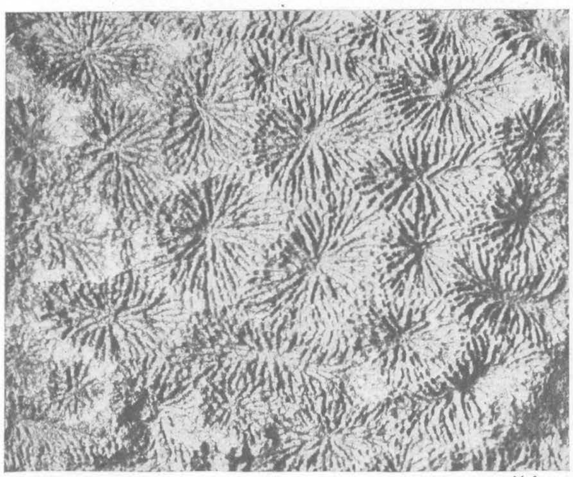
3. Calices of a paratype, × 6.

4. Calices of a second paratype, × 6.

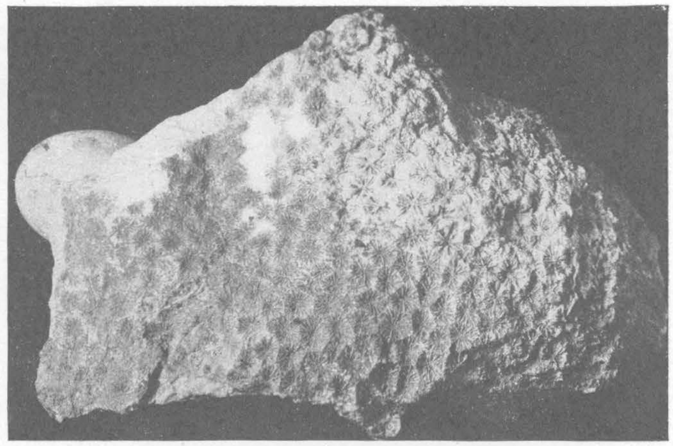
FIGURES 5, 5a, 5b, 6, 6a. *Porites carrizensis* Vaughan, n. sp., from Carrizo Creek, Cal.	375

5, 5a, 5b, Views of the holotype. 5, Corallum, natural size; 5a, a calice retouched on a photograph, × 8; 5b, the calice represented by 5a from the same photograph but without retouching.

6, 6a, Calices of a paratype. In figure 6 one calice has been retouched on the photograph; figure 6a is from a photograph on which none of the calices were retouched.



1 ×4



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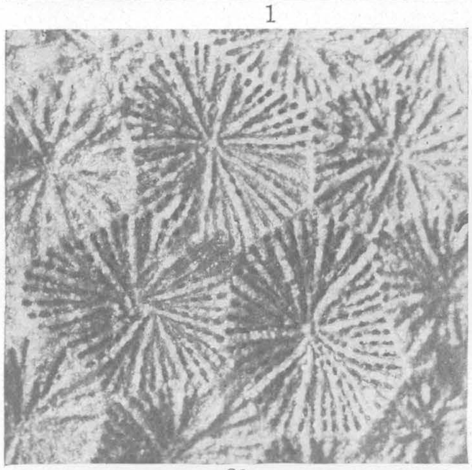
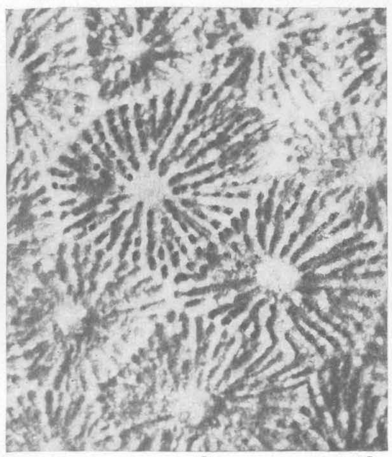
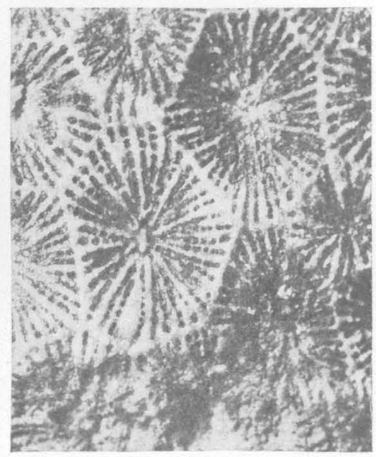


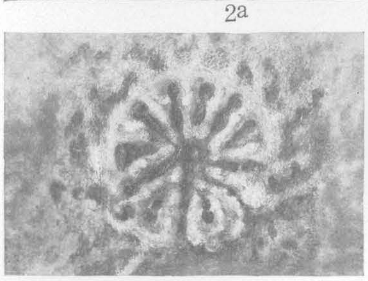
2a ×6



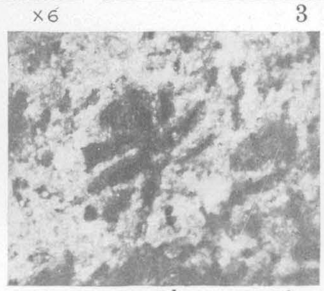
3 ×6



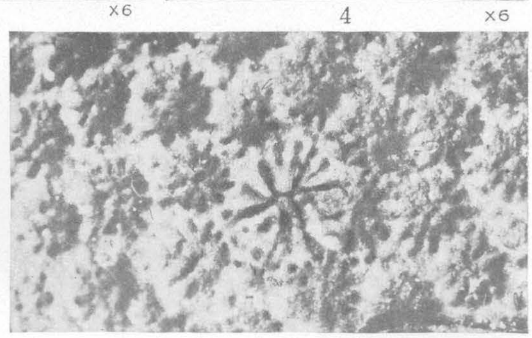
4 ×6



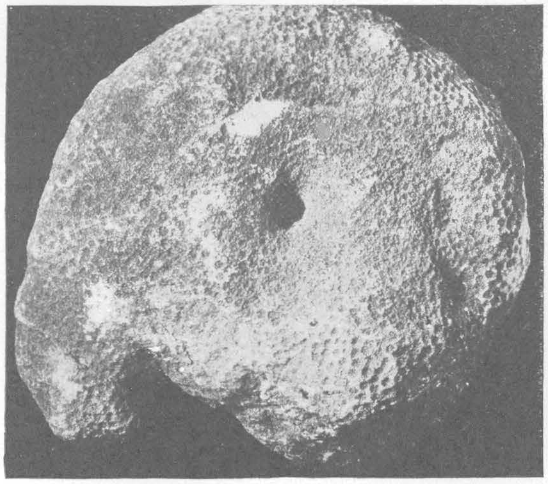
5a ×8



5b ×8



6 ×8



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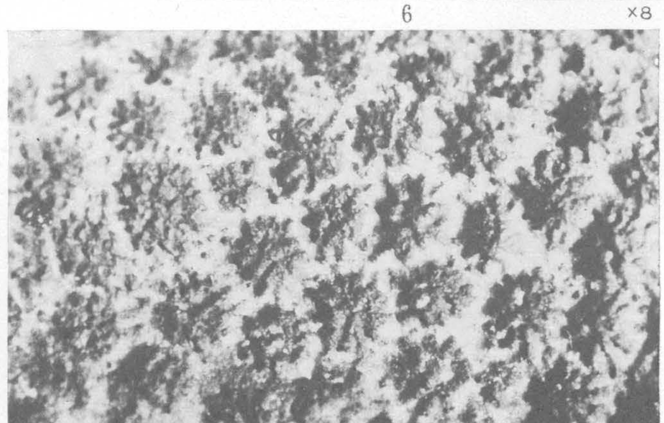

6a ×8

REEF CORALS.

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