A DEEP WELL AT CHARLESTON, SOUTH CAROLINA.

By Lloyd William Stephenson.

INTRODUCTION.

A deep well at Charleston, S. C., completed in May, 1911, has furnished valuable information in regard to the stratigraphy of the Cretaceous and younger deposits underlying that city. The well is owned by the Charleston Consolidated Railway & Lighting Co. and is at the company's gas works at the foot of Charlotte Street, near the shore of Cooper River. The well samples and the well log from which the geologic data contained in this report were obtained were sent to T. Wayland Vaughan, of the United States Geological Survey, by I. N. Knapp, engineer in charge. The driller was H. O. Hendricks. Drilling was begun January 31, 1911, and the well was completed May 15, 1911. The total depth of the well is 2,001 feet (2,007 feet below the top of the casing).

METHOD EMPLOYED IN DRILLING.

The well was drilled by the hydraulic rotary method,[1] by which a drill pipe with a drill or bit belonging to one of several types attached at the lower end is rotated by machinery and at the same time water is forced down on the inside of the drill pipe to the bottom of the well and up again to the surface between the outside of this pipe and the wall of the hole. The materials loosened by the rotating bit are carried in suspension to the surface by the forced current of circulating water. When the bit is penetrating loose, caving sands, the water, before it is introduced into the drill pipe, is mixed with clay until it forms a rather thick slush. The pressure of the column of muddy water as it is being raised to the surface on the outside of the drill pipe forces the slush into the interstices of the sands that form the wall of the boring, thus plastering the wall and producing a sort of mud casing, which usually prevents serious caving. It is expected that the material loosened by the bit and carried to the surface by the ascending current will be mixed with the material used to form the slush and also with such material as, in spite of the mud casing, may chance to cave from the walls of the boring. Samples of the mixture thus formed are obtained by passing the emerging stream through a series of screens, or by catching the slush in a vessel and washing out the suspended materials. In this manner fossils and fragments of the harder strata penetrated may be obtained. The softer sands, clays, and marls invariably have their character changed and more or less obscured by the mixing process. As the bit is rotated clay or limy mud frequently adheres to it; and in this material fragments of rock or fossil remains are sometimes caught and when the drill pipe is drawn from the well for the purpose of sharpening or renewing the bit samples of the adhering mud and its contents may be procured.

Fossils obtained from a well drilled by this process, even if the material containing them is a mixture derived from several geologic horizons, may still have definite value in correlation, for a fossil must have come either from the depth at which it was taken or from some higher level; it could not have come from a lower level. Therefore, if fossils characteristic of a certain zone are taken at a given depth the zone must have been penetrated at that depth or at a higher level.

In the samples from the Charleston well there is evidence of considerable mixing due to caving, but many of the samples contain fragments of rock which appear to reveal accurately the character of the harder strata penetrated at the depths indicated, and many of them contain fossils which appear to have come from approximately the depths indicated by their labels

[1] A more detailed description of this method is given by Isaiah Bowman in U. S. Geol. Survey Water-Supply Paper 257, pp. 70–75, 1911.

and which are sufficiently well preserved to permit their identification. Many of the samples contain a mixture of shells of Pliocene or Pleistocene age, originally derived from strata penetrated in the first 85 feet of the boring, the mixing having been effected in part through the slush used to form the mud casing and in part by the caving of the walls of the well. The nature of the fossils and their condition of preservation are such that most of them are easily distinguishable from the older fossils, obtained at greater depths, and for this reason they do not interfere seriously with the interpretation of the remainder of the section.

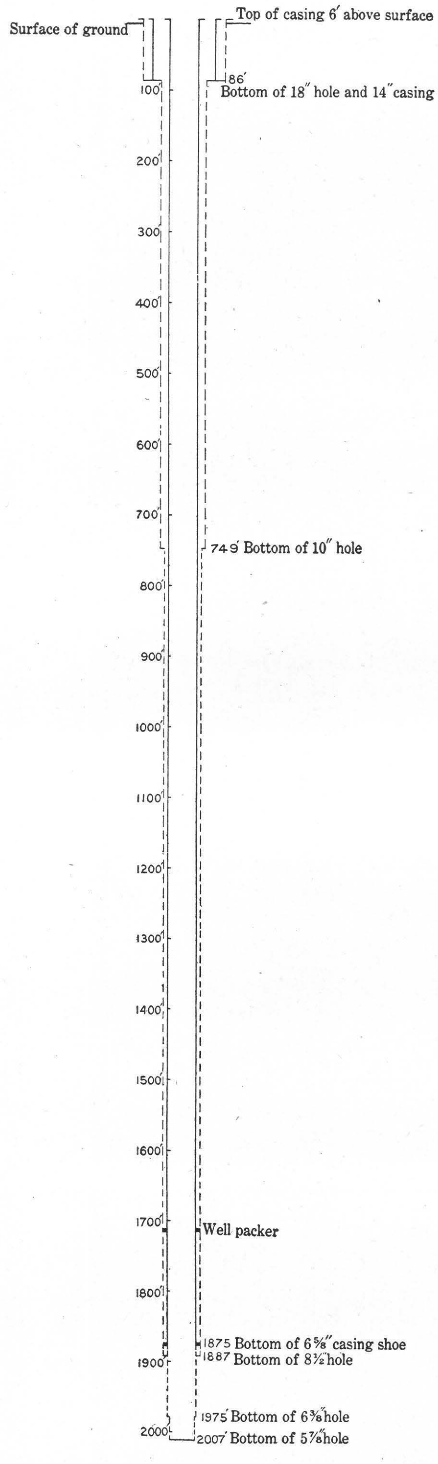

FIGURE 10.—Diagram of well at Charleston, S. C., showing size of hole and length of casings inserted. All the measurements of depths were made from the top of the rotary jaws, which stood 6 feet above the surface of the ground.

The diameter of the hole to various depths and the size and length of casings inserted are indicated diagrammatically in figure 10. The well was completed in 90 working days of 10 hours each, the time including that required for inserting casing, fishing for lost tools, and making all necessary repairs.

PRACTICAL RESULTS.

QUANTITY AND TEMPERATURE OF THE WATER.

The results of the undertaking are given in the following statement, which is quoted in substance from the original log furnished by I. N. Knapp, engineer in charge:

On May 16, the day after drilling was discontinued, clear water was pumped into the well in the same manner that the slush was pumped during the process of drilling. The temperature of the water emerging as a result of the forced overflow thus procured was 66° F. A natural flow soon started, and by evening the temperature of the water had increased to 85° F. and it was flowing at the rate of 100 to 150 gallons a minute.

On May 17 the flow increased, as did also the temperature, and fragments of shale and micaceous sand were brought up in suspension.

On May 18 the flow was irregular, varying with the amount of shale and sand brought up in suspension.

On May 19 the water was flowing from the well at a rate sufficient to fill a 50-gallon barrel in 15 seconds. The water was muddy and at times carried much sand and shale in suspension.

On June 3 the temperature of the water as it emerged from the well was 99.75° F. The flow of the water, which rose to a height of 11 feet above mean low-water level, was sufficient to fill a 50-gallon barrel in 7 seconds, or at the rate of 617,143 gallons a day. The water would rise in a pipe and flow a small stream at a height of 75 feet above mean low-water level. The water was still somewhat muddy.

ECONOMIC VALUE OF THE WATER.

According to R. B. Dole, of the United States Geological Survey, the analysis indicates an extremely soft water, softer than the waters from the Chisholm mill well (depth, 425 feet) and the old Wentworth Street well (depth, 1,260 feet). (See analyses in table on p. 93.) The water would deposit no scale in boilers and under ordinary conditions would cause no corrosion; if too strongly concentrated by continuous evaporation it might cause foaming, but this could be obviated by regular blowing off. Nothing in the analysis indicates that the water would be harmful for drinking, though it doubtless has a slight mineral taste.

The object in drilling the well was to obtain water for a boiler supply at the gas works and, according to Mr. Knapp, a practical test has shown that the water is satisfactory for this purpose.

SCIENTIFIC RESULTS.

THE WELL RECORD.

A record of the well, compiled from a set of well samples and a well log furnished by Mr. Knapp, the engineer in charge, is given below. The fourth column gives the source of the samples as recorded by the engineer and additional information furnished by him concerning the character of the strata from which some of the samples were taken; the fifth column contains the writer's description of the samples; the sixth, seventh, and eighth columns constitute the well log, which was prepared by Mr. Knapp as the drilling progressed and which records his impression of the character of the materials penetrated.

The materials penetrated in the well are of marine origin and consist of sands, clays, marls, and limestones. The sands are either soft, incoherent beds or layers in various stages of induration, the hardest being a quartzite-like rock. They are in greater or less degree calcareous. Many of the samples are glauconitic and some are micaceous. The clays are likewise either soft unconsolidated beds or layers in various stages of compactness, the hardest being almost shaly. They are more or less calcareous and usually contain some mica. The limestones occur chiefly in the Eocene portion of the section. Some of the layers appear to be fairly pure, but the rock in most of the samples contains more or less sand. The drill penetrated many beds of shell marl.

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.

[Engineer in charge, I. N. Knapp; driller, H. O. Hendricks. Drilling begun Jan. 31, 1911; well completed May 15, 1911.]

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.[a]		
						Material.	Thickness in feet.	Depth to base in feet.
Quaternary.	Pleistocene.					Length of casing protruding above surface of ground.	6	6
						Cinders, bricks, and tar	10	16
		1	40	From overflow.[b]	Dark-gray, finely arenaceous and micaceous clay, with a few shells and fragments of lignite.	Layers of spongy material, blue clay, and shells, with roots and bits of wood.	44	60
		2	62	From overflow.	Very coarse quartz sand with numerous fragments of shells and a few well-preserved shells.	An abundance of broken shells with sand.	2	62
		3	73-75	From overflow.	Chiefly fragments of shells but contains numerous well-preserved shells. Includes a small percentage of coarse quartz sand.			
Tertiary.	Pliocene.	4	82-83	Concentrated from overflow.	Same as sample No. 3 but contains small chunks of greenish-yellow sand and small black phosphatic pebbles.			
	Uppermost Eocene or Oligocene. Cooper marl.	5	86	Mud from bit.	Chunks of greenish-gray soft, slightly sandy and argillaceous limestone or marl with Foraminifera and nodules of dark-gray calcareous phosphatic sandstone. (See list of Foraminifera in table on pp. 79-80.)			
		6	102	Mud from bit.	Same as sample No. 5. (See list of Foraminifera in table on pp. 79-80.)	Layers of marl and some shells with nodules of phosphate rock.	88	150
		7	200	Mud or cuttings from overflow.	Greenish-gray calcareous sand resembling Nos. 5 and 6 in color, with some Foraminifera and some shells. (See list of Foraminifera in table on pp. 79-80.)			

[a] All the measurements given in this record were made from the top of the rotary jaws as a datum plane. As the top of the rotary jaws was 6 feet above the surface of the ground the exact depth of the well below the surface is 2,001 feet instead of 2,007 feet. The top of the rotary jaws was 14½ feet above mean low water level.

[b] The term overflow, as used in this well record, means the flow of water emerging from the mouth of the well during the process of drilling, after its passage under pressure from the pumps, down the interior of the drill pipe, and up again to the surface between the outside of the drill pipe and the wall of the hole.

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Tertiary—Continued.	Uppermost Eocene or Oligocene—Continued. Cooper marl—Continued.	8	220	Mud from bit.	Same as samples Nos. 5 and 6; contains Foraminifera and a few pelecypods. (See list of Foraminifera in table on pp. 79–80.) (From this depth to the bottom of the well nearly all the samples contain a few Recent, Pleistocene, or Pliocene shells, which doubtless represent mixtures resulting from the caving of the walls in the upper 85 feet of the well.)	Layers of marl with streaks of shells. Very hard whitish limestone.	109 1	259 260
	Eocene. Mount Hope marl of Sloan (?).	9	262–263	Concentrated from overflow; hard limestone rock.	Fragments of gray, rather soft limestone or marl; contains Nodosaria cf. *raphinistrum;* Cristellaria 1, 2, 6, 7, and 9.			
		10	270	Mud from bit; hard drilling, about 6 inches per hour.	Chunks of gray limy mud, derived from limestone.			
		11	290	Concentrated from overflow.	Fragments of rather soft limestone or marl with a few echinoid spines; contains also Nodosaria 3 and Cristellaria 10.			
		12	299	Mud from bit; hard lime rock.	Chunks of gray limy mud derived from limestone.	Alternate layers of limestone and marl; hard to medium drilling. Hard rock Very soft material	68 5 4	328 333 337
		13	348–350	Concentrated from overflow.	Fragments of gray sandy, rather soft limestone or marl with a few echinoid spines.	Marl Hard rock	11 6	348 354
		14	361	Mud from bit; very hard.	Chunks of bluish-gray calcareous, argillaceous, and sandy mud, with chunks of dark calcareous sandstone, probably derived from sandy limestone.	Medium hard rock	7	361
		15		Sample missing.				
		16	362	Mud from bit; hard drilling, about 1 inch per hour.	Apparently a sandy limestone ground to a fine white mud by the bit.	Excessively hard rock; drilled 1 inch per hour with fishtail bit.	1	362
		17	365	Concentrated from overflow.	Fragments of light-gray sandy limestone with a few echinoid spines and fragments of shells; contains also Nodosaria 11 ?.	Hard rock and flint Excessively hard rock	9 1	371 372
		18	375	Mud from bit.	Apparently a sandy limestone ground to a fine gray mud by the bit.			
		19	395	Mud from overflow.	Chunks of gray porous calcareous sandy mud, apparently a sandy limestone ground and mixed by the bit.	Hard white limestone	20	392
		20	395	Concentrated from overflow.	Fragments of light-gray sandy limestone with fragments of shells.	Layers of marl; easy drilling.	19	411
		21	427–433	Fragments of selected clay or shale from overflow.	Fragments of gray calcareous, micaceous shaly clay.	Very soft material Hard dark-gray rock Marl Very hard material Soft material with sand and shells. Very hard material Soft dark clay	2 3 5 1 3 1 7	413 416 421 422 425 426 433
		22	435	Concentrated from overflow.	Fragments of light-gray sandy limestone with numerous fragments of shells.			
		23	439–444	Concentrated from overflow; bed of shells.	Fragments of light-gray sandy limestone with numerous fragments of echinoid spines, bryozoans, and shells; contains Nodosaria 5.	Coarse-cutting rock, with shells. Shells and rock	6 5	439 444

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Tertiary—Continued.	Eocene—Continued. Mount Hope marl of Sloan (?)—Continued.	24	447	Concentrated from overflow.	Mixture of fragments of light-gray sandy limestone and darker-gray, finely arenaceous, calcareous shaly clay, with numerous shell fragments and some fragments of Bryozoa; contains Nodosaria 2 cf. *raphinistrum?* Nodosaria 5.			
		25	454	Mud and fragments of rock from bit.	Chunks of dark-gray, finely arenaceous and micaceous, calcareous clay; contains Textularia *b* cf. *sagittula*, Verneuilina *a* cf. *propinqua*, Uvigerina *a* cf. *canariensis*, Globigerina *b* cf. *æquilateralis*, Truncatulina *f* cf. *lobatula*, Polystomella, Massilina.	Dark clay or shale .... Hard rock; required 2 hours to drill with fishtail bit.	24 1	468 469
Upper Cretaceous or Tertiary.	(?)	26	478	Mud from bit.	Chunks of lighter-gray, finely arenaceous and micaceous, calcareous clay; contains Textularia *b* cf. *sagittula*, Cassidulina cf. *subglobosa*, Lagena *b* cf. *sulcata*, *Uvigerina pygmæa*, Truncatulina *f* cf. *lobatula*, Polystomella.	Soft material with shells.... Black shale or clay; no shells.	4 21	473 494
		27	500	Mud from overflow.	Chunks of greenish-gray porous sandy calcareous clay.			
		28	500	Concentrated from overflow.	Fragments of gray calcareous shaly clay with some admixture of quartz sand.			
		29	504	Sand from overflow.	Loose dark-green, highly glauconitic sand; the grains of quartz are clear and angular; contains Textularia *b* cf. *sagittula*, Polymorphina *d*, Sphæroidina cf. *bulloides*, Truncatulina *f* cf. *lobatula* Truncatulina *h*, Polystomella.	Variable streaks of yellow sand and marl. Layers of black sand with streaks of marl.	7 9	501 510
		30	515	Concentrated from overflow.	Fragments of gray shaly calcareous clay mixed with greenish-gray calcareous mud.			
		31	525–540	Concentrated from overflow; parts of several samples taken from between 525 and 540 feet; all much the same, clay and marls.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Foraminifera. (See list in table, pp. 79–80.)	Alternating streaks of marl and clay, some yellow, some dark gray. Very hard rock..............	26.5 .5	536.5 537
		32	544	Mud from bit, medium hard, black when wet.	Chunks of dark-gray argillaceous, glauconitic, calcareous sand.	Not described............... Hard rock....................	8 1	545 546
		33	550–570	Concentrated from overflow; average of several samples.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Cristellaria 11 cf. *clypeiformis*.			
		34	585	Concentrated from overflow.	Fragments of gray shaly, finely arenaceous micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Nodosaria 2 cf. *raphinistrum*.	Alternating layers of black and dark-gray shale, medium to hard; no shells.	41	587
		35	600	Concentrated from overflow.	Fragments of gray shaly calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl, with some sand.	Soft material................	2	589

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous or Tertiary—Continued.	(?)	36	608	Mud from bit.	Chunks of gray, finely arenaceous and micaceous, calcareous clay, with fragments of greenish-gray marl which probably fell down from the Cooper marl.	Alternating layers of medium hard dark-colored marls and shales. Bit pulled from 608 feet showed mica in mud. Very hard material	36 1	625 626
		37	630–660	Concentrated from overflow. Average of several samples; formation variable, thin strata, hard to soft, in color yellowish, light gray, dark gray, black.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Foraminifera. (See list in table, pp. 79–80.)			
		38	661	Mud from bit.	Chunks of gray, finely arenaceous and micaceous, calcareous clay.			
		39	680–685	Concentrated from overflow.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Nodosaria 15.	Thin layers of light-colored marl and limestone, medium hard to hard.	75	701
		40	702	Mud from bit; very hard dark-blue limestone.	Chunks of gray calcareous clay with white streaks of lime; contains Nodosaria 15 and Cristellaria 11 cf. *clypeiformis*.	Very hard blue limestone	1.5	702.5
		41	725	Concentrated from overflow.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl, also loose sand; contains Cristellaria 11 cf. *clypeiformis*.	Variable layers of light-colored clay or marl Soft grayish-white clay in overflow. Not described	31.5 2 5	734 736 741
		42	742	Mud from bit; dark gray, almost black when wet; very hard.	Chunks of gray calcareous clay with white streaks of lime; contains Nodosaria 15 and Cristellaria 11 cf. *clypeiformis*.	Very hard material; required 10 hours continuous drilling with fishtail bit.	3	744
Upper Cretaceous.	Peedee sand (?).	43	750	Mud from overflow.	Gray calcareous, slightly argillaceous, glauconitic sand; contains Clavulina cf. *angularis*, Nodosaria 2 cf. *raphinistrum* ?, Nodosaria 14, Nodosaria 15, Cristellaria 11 cf. *clypeiformis*, Vaginulina.	Hard material; medium to hard drilling. Hard rock Alternating thin layers of medium to hard rock. Soft material, possibly sand.	18 5 24 2	762 767 791 793
		44	805–808	Sandrock cuttings, concentrated from overflow.	Very coarse quartz sand with fragments of gray glauconitic sandstone and numerous small black phosphatic pebbles.	Marl White sandy material	12 3	805 808
		45	810	Mud from overflow; in hard rock.	Gray porous calcareous clay with some sand; contains Clavulina cf. *angularis*, Nodosaria 14, Cristellaria 11 cf. *clypeiformis*, Vaginulina.			
		46	840–850	Cuttings concentrated from overflow.	Gray shaly, finely arenaceous clay with numerous small black phosphatic pebbles and some sand; contains Clavulina cf. *angularis*, Cristellaria 11 cf. *clypeiformis*.			
		47	855–860	Cuttings concentrated from overflow.	Same as sample No. 46, except that black pebbles are not numerous; contains Clavulina cf. *angularis*, Nodosaria 14, Cristellaria 11 cf. *clypeiformis*.			
		48	870–890	Selected from overflow; average.	Same as sample No. 47; contains Clavulina cf. *angularis*, Nodosaria 14, Nodosaria 15, Cristellaria 11 cf. *clypeiformis*.	Layers of light-gray to black marl; easy drilling; variable materials.	110	918

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued.	Peedee sand.	49	920	Mud from overflow.	Gray calcareous, slightly argillaceous sand; contains Clavulina cf. *angularis*, Nodosaria 15, Cristellaria 11 cf. *clypeiformis*.			
		50	920	Same as sample No. 49 with mud washed out.	Gray shaly calcareous, finely arenaceous clay with some sand; contains Clavulina cf. *angularis*, Ostrea sp. (young individual), fragments of *Anomia argentaria* Morton, and tooth of *Corax falcatus* Agassiz.	Greenish shale	4	922
		51	950	Mud from overflow.	Gray calcareous, argillaceous sand.			
		52	950	Same as sample No. 51 with mud washed out.	Gray shaly, finely arenaceous clay with a few small black phosphatic pebbles and some sand; contains Nodosaria 16 cf. *inflexa*, Ostrea sp. (young individual), and *Anomia argentaria* Morton.	Uniformly hard material, probably sandy limestone. Marl; easy drilling Hard limestone	38 14 4	960 974 978
		53	1,000	Mud from overflow.	Gray calcareous, slightly argillaceous sand.	Marl Probably cemented shells; rough drilling.	14 2	992 994
		54	1,000	Concentrated from mud; same as sample No. 53.	Coarse sand with numerous fragments of gray shaly calcareous clay; contains Ostrea sp. (young individual), and tooth of *Corax falcatus* Agassiz?	Marl	6	1,000
		55	1,015–1,030	Concentrated from overflow.	Gray shaly calcareous, finely arenaceous clay with sand and sandstone fragments; contains *Ostrea falcata* Morton, *Ostrea plumosa* Morton, *Anomia argentaria* Morton, and tooth of *Corax falcatus* Agassiz?	Sandrock	15	1,015
		56	1,035–1,045	Concentrated from overflow.	Loose light-gray calcareous sand with scattered grains of glauconite; contains *Ostrea falcata* Morton.	Thin layers of shale, sandrock, and marl. Hard material, probably sandrock.	20 4	1,035 1,039
		57	1,055–1,058	Mud from overflow.	Chunks of gray calcareous, argillaceous, slightly glauconitic sand.			
		58	1,055–1,058	Concentrated from overflow.	Fragments of gray shaly calcareous, finely arenaceous clay, with considerable fine, slightly glauconitic gray sand and a few small black phosphatic pebbles; contains *Anomia argentaria* Morton (fragment).			
		59	1,090–1,100	Concentrated from overflow; uniformly hard, sandy clay.	Fine light-gray, slightly glauconitic sand with small fragments of gray calcareous shaly clay.	Layers of light to dark gray clay with thin layers of sandrock.	61	1,100
		60	1,130–1,140	Concentrated from overflow; easy drilling; uniform material, consisting of sandy clay, with some shells.	Same as sample No. 59; contains *Lima reticulata* Forbes (fragment).			
		61	1,150–1,200	Selected from concentrates.	Gray shaly, finely arenaceous and micaceous, calcareous clay, with a few chunks of greenish-gray calcareous clay and some sand; contains *Belemnitella americana* (Morton)? (fragment).	Dark-gray and blue sandy shale; good drilling.	83	1,183

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the Company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued.	Peedee sand—Continued.	62	1,230–1,250	Concentrated and selected; fossils, pyrites, and marls.	Same as sample No. 61, with chunks of greenish-gray marl which probably fell down from the Cooper marl; contains the coral Trochocyathus sp. (aff. *T. woolmani* Vaughan), identified by T. Wayland Vaughan.	Sandy marl with reddish fossil shells. Hard rock	57 1	1,240 1,241
		63	1,259	Mud from bit; black and grayish when wet.	Chunks of dark-gray, finely arenaceous and micaceous clay with some sand.	Not described	19	1,260
		64	1,262–1,275	Mud from overflow.	Gray sandy, slightly argillaceous, calcareous sand.			
		65	1,262–1,275	Same as sample No. 64 but washed and concentrated.	Gray coarse, slightly glauconitic sand and gray shaly, finely arenaceous and micaceous clay.	Medium-hard rock Soft sandrock	2 14	1,262 1,276
		66	1,306	Mud from bit.	Chunks of gray, finely arenaceous and micaceous clay.			
		67	1,300–1,306	Washed from overflow and selected.	Fragments of gray calcareous shaly clay and gray calcareous sandstone with a few small black phosphatic pebbles.	Soft to medium-hard layers of marl and sandstone.	30	1,306
		68	1,310–1,320	Concentrated from overflow.	Gray calcareous sand and fragments of sandstone with fragments of gray shaly calcareous clay.	Hard rock Variable layers of shale and sandy shale, with some shells and fish teeth.	2 28	1,308 1,336
		68a	1,340–1,360	Mud from overflow; medium-hard sandy rock; good drilling.	Loose gray calcareous, slightly glauconitic and micaceous sand, with chunks of slightly indurated sand.			
		69	1,340–1,360	Washed and selected from overflow; same as sample No. 68.	Chunks of gray calcareous, slightly glauconitic sandstone, and fragments of gray shaly calcareous clay; contains Ostrea sp. (young individual) and Exogyra sp. (fragments of the small valve).			
		70	1,375–1,400	Concentrated and selected; shells 1,375 to 1,381 feet.	Coarse gray sand and fragments of calcareous sandstone with a few fragments of gray shaly calcareous clay; fragments of shells numerous; contains *Ostrea plumosa* Morton; Ostrea sp. (young individuals), Exogyra sp. (fragments), and tooth of Lamna?; shells from 1,375 to 1,381 feet.	Medium-hard sandy rock; uniform drilling. Hard rock Soft material with broken shells. Probably sandy marl; good drilling. Hard rock	36 3 6 35 2	1,372 1,375 1,381 1,416 1,418
		71	1,420–1,430	Concentrated and selected from overflow.	Same as sample No. 70.	Not described Very hard rock	12 1	1,430 1,431
		72	1,440–1,450	Concentrated and selected from overflow; shells.	Same as samples Nos. 70 and 71; contains *Ostrea plumosa* Morton, Exogyra sp. (fragments), *Anomia argentaria* Morton, and a small shark tooth.			
		73	1,460–1,470	Concentrated and selected from overflow.	Similar to samples Nos. 70–72 but contains more loose sand.			
		74	1,480–1,490	Concentrated and selected from overflow.	Fragments of gray, finely arenaceous and micaceous, calcareous clay and gray argillaceous sandstone.			
		75	1,500–1,510	Concentrated and selected from overflow.	Same as sample No. 74.			
		76	1,514	Mud from bit; very hard material.	Chunks of dark-gray, finely arenaceous and micaceous clay with some sand.	Layers of soft black sticky clay with medium to hard shales and sandstones in thin layers.	88	1,519

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued.	Peedee sand—Continued.	77	1,540–1,550	Cuttings selected from overflow.	Gray shaly, finely arenaceous and micaceous clay and fragments of soft gray calcareous, argillaceous, slightly glauconitic sandstone; contains *Pecten venustus* Morton.	Uniformly hard shale Very sticky shale Rock	12 16 5	1,531 1,547 1,552
	Black Creek formation (?).	78	1,550–1,560	Shale and bits of pyrites selected from overflow.	Same as sample No. 77.			
		79	1,560–1,570	Selected from overflow.	Same as samples Nos. 77 and 78.	Layers of medium to hard shales with iron pyrites and layers of black shales; required frequent spudding.	63	1,615
		80	1,590–1,600	Cuttings from overflow.	Same as samples Nos. 77–79 but contains some sand.	Very hard rock	2	1,617
		81	1,620–1,630	Cuttings from overflow.	Similar to samples Nos. 77–80 but contains much sand.	Variably thin strata of dark shale.	23	1,640
		82	1,640–1,642	Mud from overflow.	Same as samples Nos. 77–79; contains some fragments of shells.	Broken shells Marl Very hard rock	2 3 3	1,642 1,645 1,648
		83	1,660–1,670	Selected from overflow.	Same as samples Nos. 77–79; contains Ostrea sp. (young individual) and two teeth of fish.			
		84	1,660–1,670	Mud from overflow; soft; easy drilling.	Loose gray calcareous sand with numerous fragments of gray shaly calcareous clay.			
		85	1,700–1,705	Selected from overflow.	Same as samples Nos. 77–79.	Shales in layers; easy drilling. Hard rock, probably limestone. Probably limestone and flint; very hard and rough drilling.	46 13 4	1,694 1,707 1,711
		86	1,720–1,723	Concentrated from overflow; very hard.	Gray shaly, finely arenaceous and micaceous clay, with fragments of gray calcareous sandstone; contains a shark tooth.	Layers of hard rock; rough drilling.	13	1,724
		87	1,720–1,723	Mud from overflow; same as sample No. 86.	Loose light-gray glauconitic, calcareous sand, with fragments of gray shaly clay.			
	Black Creek formation.	88	1,725–1,730	Mud from overflow; hard to very hard, with one soft streak.	Same as sample No. 87; contains Nodosaria 6 and 17, *Ostrea cretacea* Morton? (young individual), and fragments of *Pecten quinquecostatus* (Sowerby).	Soft, sticky whitish clay	5	1,729
		89	1,736	Mud from bit.	Chunks of gray argillaceous, micaceous, calcareous sand; contains Crassatellites sp. (cast).			
		90	1,763–1,767	Concentrated from overflow; very hard, with one soft streak.	Loose gray calcareous, slightly glauconitic sand, with fragments of gray calcareous shaly clay.	Thin layers of hard rock (rough drilling) with thin streaks of soft material. The layers are a few inches to 2 feet thick. Whitish clays and shales, with hard lumps and layers. Soft white shales	30 15 2	1,759 1,774 1,776
		91	1,790–1,800	From overflow; hard rock.	Same as sample No. 90.			
		92	1,800–1,812	Selected from overflow (from 1,802 to 1,804 feet lost water; probably water sand, sandrock, and thin streaks of marl).	Loose coarse quartz sand, with fragments of gray calcareous shaly clay; contains Bryozoa?, *Ostrea cretacea* Morton, and a coprolite.	Hard black marl, with nodules and lumps; rough drilling. Sands and shales; lost water in drilling.	25 2	1,801 1,803

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.	Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
					Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued. Black Creek formation—Continued.	93	1,813	Mud from bit.	Chunks of gray calcareous, finely arenaceous and micaceous clay.			
	94	1,815–1,818	Selected from overflow.	Chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl, and chunks of hard gray glauconitic sandstone.	Layers of excessively hard limestone with thin layers of sand, black shale, pyrites, shells, and fossil wood. Soft yellow sandrock	12 3	1,815 1,818
	94a	1,830?	Questionably from this depth.	Chunk of hard gray, slightly calcareous sandstone or quartzite.	Not described	12	1,830
	95	1,832	Mud from bit.	Chunks of finely arenaceous and micaceous calcareous clay, with white streaks of lime; contains fragment of *Exogyra ponderosa* Roemer?	Hard white limestone	2	1,832
	96	1,835	Mud from bit; very hard conglomeratic rock.	Same as sample No. 95.			
	97	1,835	Taken from mud on bit.	Chunk of hard gray calcareous sandstone or quartzite, with poorly preserved shell remains.			
	98	1,839	Concentrated from mud on bit; very hard; slow drilling; knots or lumps in material.	Loose, coarse sand with chunks of hard gray sandstone, a few small waterworn pebbles and chunks of gray sandstone; contains Ostrea sp. (fragment), and tooth of *Corax falcatus* Agassiz.			
	99	1,839	From mud on bit; same as sample No. 98.	Chunk of hard gray calcareous, micaceous sandstone or quartzite.			
	100	1,841	Concentrated from mud on bit.	Coarse sand with chunks of gray calcareous sandstone, gray calcareous shaly clay, a few quartz pebbles up to $\frac{7}{16}$ inch in length, and fragments of shells; contains *Hamulus onyx* Morton, *Ostrea cretacea* Morton, and undetermined pelecypod cast.	Layer of shale, conglomerate, limestone, sandstone; excessively hard, thin layers of pyrites; some layers of pyrites drilled at rate of 1 inch per hour with Sharp & Hughes bit in good order. Very hard sandy limestone; good drilling.	15 14	1,847 1,861
	101	1,862	Mud from bit.	Gray calcareous, finely arenaceous and micaceous clay.			
	102	1,862	Concentrated from mud on bit; same as sample No. 101.	Very coarse sand with chunks of gray calcareous sandstone, chunks of gray calcareous shaly clay, a few quartz pebbles up to $\frac{1}{4}$ inch in length, and shell fragments; contains *Ostrea cretacea* Morton, Gryphæa sp. (small), and *Exogyra ponderosa* Roemer?	Very hard rock	6	1,867
	103	1,887	Concentrated from mud on bit.	Same as sample No. 102; contains Ostrea sp.			
	104	1,887	Mud from bit; same as sample No. 103.	Chunks of dark-gray, finely arenaceous and micaceous clay.			
	105	1,940–1,960	Sand from overflow.	Loose gray, slightly glauconitic, calcareous sand; contains Cristellaria 12.	Hard shales which produce a sticky mud. Very soft material Medium-hard shales with thin, soft layers, probably sand; easy drilling with fishtail bit.	39 3 38	1,906 1,909 1,947
	106	1,950–1,960	Concentrated from overflow.	Loose, coarse sand with numerous small fragments of shells.	Medium-hard rock Soft to medium-hard layers of shale and sand; some sand and shell breccia in overflow.	4 23	1,951 1,974
	107	1,975	Mud from bit.	Chunks of gray calcareous, finely arenaceous and micaceous clay.	Very hard sandrock; fishtail bit would not make 1 inch per hour.	3	1,977

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued.	Black Creek formation—Continued.	108	2,000–2,005	Concentrated from overflow.	Loose, coarse light-gray sand with numerous small shell fragments.	Sandrock with much muck; fair drilling.	28	2,005
		109	1,974–2,007	Average of material brought to surface by natural flow.	Loose, medium-grained micaceous, calcareous sand with bits of lignite.			
		110	1,974–2,007	Fossil wood brought to surface by natural flow.	Lignite.			
		111	1,974–2,007	Brought to surface by natural flow.	Chunks of gray laminated micaceous, slightly calcareous clay with fine sand partings; contains comminuted vegetable fragments.			
		112	1,974–2,007	Brought to surface by natural flow.	Chunks of light-gray micaceous, calcareous sandstone or quartzite; chunks of gray calcareous shaly clay; one concretion of sandy limestone; concretions of iron pyrites; small waterworn pebble, lignite, and numerous shells and fragments of shells. Recognized fragment of small coral, Bryozoa (incrusting), Ostrea sp. nov. *a*, Ostrea sp. nov. *b*, *Ostrea cretacea* Morton, *Exogyra upatoiensis* Stephenson, Anomia sp. nov. (same as new species from Snow Hill, N. C.), and undetermined fragments of Ostreidæ.	Blue clay or shale..........	2	2,007

FOSSILS OBTAINED FROM THE WELL SAMPLES.

PROTOZOA.

The subkingdom Protozoa is represented in the well section by numerous specimens of Foraminifera, which were referred to Joseph A. Cushman for identification. The species recognized by him and their distribution in the well are indicated in the accompanying table. All measurements of depth indicated in this table and on the following pages were made from the top of the rotary jaws, which stood 6 feet above the surface of the ground:

Foraminifera from well of Charleston Consolidated Railway & Lighting Co., Charleston, S. C.

	Uppermost Eocene or Oligocene.				Eocene.						Eocene or Upper Cretaceous.									Upper Cretaceous.									
	Cooper marl.				Mount Hope marl of Sloan (?).															Peedee sand (?).					Peedee sand.			Black Creek formation.	
No. of sample	5	6	7	8	9	11	17	23	24	25	26	29	31	33	34	39	40	41	42	40	45	46	47	48	49	50	52	88	105
Depth in feet	86	102	200	220	262–263	290	365	439–444	447	454	478	504	525–540	550–570	585	680–685	702	725	742	753	810	840–850	855–860	870–890	920	920	950	1725–1730	1940–1960
Textulariidæ.																													
Textularia *a*	×																												
b cf. sagittula	×	×	×	×						×	×	×																	
c cf. gramen				×																									
d cf. sagittula var. atrata		×																											
e cf. millettii				×																									
Bolivina *a*	×												×																
b	×	×		×																									
d		×																											
e		×																											
f cf. reticulata	×	×	×	×									×																
g				×																									
Bulimina inflata	×																												
b		×											×																
buchiana			×										×																

Foraminifera from well of Charleston Consolidated Railway & Lighting Co., Charleston, S. C.—Continued.

	Uppermost Eocene or Oligocene.				Eocene.						Eocene or Upper Cretaceous.									Upper Cretaceous.									
	Cooper marl.				Mount Hope marl of Sloan (?).															Peedee sand (?).					Peedee sand.			Black Creek formation.	
No. of sample	5	6	7	8	9	11	17	23	24	25	26	29	31	33	34	39	40	41	42	43	45	46	47	48	49	50	52	88	105
Depth in feet	86	102	200	220	262–263	290	365	439–444	447	454	478	504	525–540	550–570	585	680–685	702	725	742	750	810	840–850	855–860	870–890	920	920	950	1725–1730	1940–1960
Gaudryina *a*		×																											
b		×																											
c	×	×																											
Verneuilina *a* cf. propinqua		×								×																			
Cassidulina cf. subglobosa				×							×																		
Clavulina *a* cf. parisiensis	×		×																										
cf. angularis																				×	×	×	×	×	×	×			
Chilostomellidæ.																													
Chilostomella ovoidea				×																									
Lagenidæ.																													
Lagena *a*	×			×																									
b cf. sulcata	×	×	×								×																		
c			×																										
d cf. staphyllearia				×																									
Nodosaria 1 cf. sagrinensis	×												×																
2 cf. raphinistrum	×	×	×		×				?				×			?					?								
3		×		×		×																							
4		×		×									×																
5		×						×	×																				
6		×																										×	
7		×																											
8 cf. lævigata		×																											
9 cf. communis		×											×																
10				×																									
11				×			?																						
12				×																									
13 cf. hirsuta		×																											
14																				×	×		×	×	×				
15																×	×		×	×				×					
16 cf. inflexa																											×		
17																												×	
Cristellaria 1	×				×																								
2		×			×								×																
3 cf. latifrons		×																											
4 cf. italica		×																											
5 cf. convergens		×																											
6		×		×	×																								
7		×		×	×																								
8		×		×																									
9					×																								
10						×							×																
11 cf. clypeiformis														×			×	×	×	×	×	×	×	×	×				
12																													×
Frondicularia *a*		×	×	×																									
b				×									×																
Marginulina	×	×	×																										
Polymorphina *a*	×	×																											
b cf. oblonga		×	×	×																									
c cf. elegantissima		×																											
d		×										×	×																
Uvigerina *a* cf. canariensis	×	×	×	×						×			×																
pygmæa *b*	×	×	×	×							×		×																
Vaginulina																				×	×								
Globigerinidæ.																													
Globigerina *a* cf. dubia	×	×	×	×																									
b cf. æquilateralis	×	×	×	×						×																			
Sphæroidina cf. bulloides	×	×	×	×								×	×																
Rotalidæ.																													
Pulvinulina cf. oblonga	×	×																											
Rotalia	×	×	×	×																									
Truncatulina *a*	×	×	×										×																
b	×	×																											
c cf. reticulata	×	×	×	×																									
d	×	×																											
e cf. akneriana	×	×	×	×																									
f cf. lobatula	×	×	×	×						×	×	×	×																
g			×	×																									
h			×	×								×																	
Nummulitidæ.																													
Polystomella	×	×	×	×						×	×	×	×																
Nonionina cf. umbilicatula	×	×	×																										
Miliolidæ.																													
Massilina	×	×	×	×						×			×																

In regard to the Foraminifera listed in the table, Dr. Cushman says:

The Foraminifera of the deep well at Charleston have been examined carefully down to station 50 (depth 920 feet), where the known Cretaceous begins, in order to determine, if possible, the limits of the Cretaceous in the questionable sections above. The samples of the Cooper marl, Nos. 5, 6, 7, and 8, were first carefully studied. These samples contain a very rich foraminiferal fauna, as will be seen by the accompanying chart of distribution. Of the 81 species recorded from the well 71 occur in these four samples. Sample 6 was much the richest in species, containing 50 of the 71 Cooper marl species. In general it is such an assemblage as may have occurred in water ranging in depth from 100 to 200 fathoms. It is most marked by the practical absence of the Miliolidæ, only one species being present and that allied to the forms found in the deeper water of present oceans.

A study of the washed material from stations 25 to 50, the questionable section, soon showed that material from several horizons had been mixed. As noted by those who had previously examined the lithology of this material, the Cooper marl had dropped down in the boring and had been mixed nearly throughout the samples taken below, so that it became necessary to eliminate the Cooper marl species from each sample. The occurrence of these species was noted and is charted for samples 25, 26, 29, and 31, but it was soon seen that these species represented merely the material which had accidentally dropped from above, so that the charting was not continued. These species occur similarly in the samples down to 50, where the known Cretaceous begins.

It became apparent that the upper part of the section was of slight interest as far as the Foraminifera were concerned, but in sample 39 other species were found. These, however, are too few and poor to afford very definite information, but when sample 43 was reached a marked change was shown in both the physical character of the test and in the species. At this level there were specimens of the genus Vitrewebbina attached to specimens of Cristellaria and Nodosaria. This genus is recorded from the Cretaceous of New Jersey by Bagg. These and certain other forms occurring at this level seem to show that the Cretaceous strata here lie as high as the 750-foot level. The same species characterize the samples taken immediately below.

Many of the forms, especially those of the Cooper marl, have been referred to known species, but the whole series shows marked differences from allied known faunas and the material must be carefully studied in conjunction with that from other localities for final determination. Meanwhile the data showing the distribution of the fossils in the well samples are available for use.

CŒLENTERATA.

A coral identified by Vaughan as Trochocyathus sp. aff. *T. woolmani* Vaughan was found in sample 62, depth 1,230–1,250 feet, and a fragment of an unidentified coral was found in sample 112, depth 1,974–2,007 feet.

ECHINODERMATA.

The spines of unidentified echinoderms were found in four of the samples as follows: Sample 11, depth 290 feet; sample 13, depth 348–350 feet; sample 17, depth 365 feet; sample 23, depth 439–444 feet.

VERMES.

Hamulus onyx Morton, a species regarded as belonging to the subkingdom Vermes, was found in sample 100, depth 1,841 feet.

MOLLUSCOIDEA.

The subkingdom Molluscoidea is represented in the well by Bryozoa, fragments of which were contained in samples 22, 23, and 24. In these samples R. S. Bassler has recognized the following species:

Sample 22, depth 435 feet, contains Entalophora cf. *macrostoma.*

Sample 23, depth 439 to 444 feet, contains Heteropora sp. nov., Escharinella (cf. *altimuralis* U. and B. of the Rancocas formation, but has smaller pores), Amphiblestrum (cf. *heteropora* G. and H. of the Rancocas formation), Lichenopora (cf. *grignonensis* Milne-Edwards).

Sample 24, depth 447 feet, contains Heteropora sp. nov., Escharinella (cf. *altimuralis* U. and B. of the Rancocas formation, but has smaller pores).

MOLLUSCA.

MOLLUSKS FROM THE PLEISTOCENE AND PLIOCENE.

Fossil mollusks were found in samples 1 to 4, as follows:

Sample 1, depth 40 feet, contained a few shells.

Sample 2, depth 62 feet, contained numerous fragments of shells and a few well-preserved shells.

Sample 3, depth 73–75 feet, consisted chiefly of fragments of shells with numerous well-preserved shells.

Sample 4, depth 82–83 feet, consisted chiefly of fragments of shells, with numerous well-preserved shells.

The fossils from samples 1 to 3 are of Pleistocene age and those from sample 4 are of Pliocene age. (See pp. 71, 85.)

Many of the samples taken between the depth of 86 feet and the bottom of the well contained a few Pleistocene or Pliocene shells, which doubtless represented mixtures resulting from the caving of the walls in the upper 86 feet of the well. Most of these fossils were easily distinguishable from the older Eocene and Cretaceous fossils, and since their mention would serve only to confuse the reader they have been disregarded in all that follows.

MOLLUSKS FROM THE EOCENE.

The samples from the strata of uppermost Eocene or Oligocene age between the depths of 86 and 220 feet (samples 5 to 8, inclusive) and the samples from strata of undoubted Eocene age penetrated in the well between the depths of 262 and 447 feet (samples 9 to 24, inclusive) contained a few fragments of unidentified mollusks in addition to numerous shells which were obviously present as a mechanical mixture from the upper 86 feet of the boring.

MOLLUSKS FROM THE CRETACEOUS.

Exclusive of the shells which were obviously present as a mechanical mixture from the upper 86 feet of the section, samples 50 to 112, representing depths from 920 to 2,007 feet, contained the species of fossil mollusks listed in the following table:

Cretaceous mollusks from the deep well of the Charleston Consolidated Railway & Lighting Co., Charleston, S. C.

No. of sample Depth in feet	50 920	52 950	54 1,000	55 1,015–1,030	56 1,035–1,045	58 1,055–1,058	60 1,130–1,140	61 1,150–1,200	69 1,340–1,360	70 1,375–1,400	72 1,440–1,450
Ostrea falcata Morton				×	×						
plumosa Morton				×						×	×
cretacea Morton											
sp. nov. *a*											
b (probably undescribed)											
(young individuals)	×	×	×						×	×	
(fragments)											
Gryphæa sp											
Exogyra ponderosa Roemer											
upatoiensis Stephenson											
(fragments)									×	×	×
Pecten venustus Morton											
quinquecostatus Sowerby											
Lima reticulata Forbes							×				
Anomia argentaria Morton	×	×		×		×					×
sp. nov. (same as sp. nov. from Snow Hill, N. C.)											
Crassatellites sp. (cast)											
Undetermined casts of pelecypods											
Belemnitella americana (Morton)?								×			

No. of sample Depth in feet	77 1,540–1,550	83 1,660–1,670	88 1,725–1,730	89 1,736	92 1,800–1,812	95 1,832	98 1,839	100 1,841	102 1,862	103 1,887	112 1,974–2,007
Ostrea falcata Morton											
plumosa Morton											
cretacea Morton			?		×			×	×		×
sp. nov. *a*											×
b (probably undescribed)											×
(young individuals)		×									
(fragments)							×			×	×
Gryphæa sp									×		
Exogyra ponderosa Roemer						?			?		
upatoiensis Stephenson											×
(fragments)											
Pecten venustus Morton	×										
quinquecostatus Sowerby			×								
Lima reticulata Forbes											
Anomia argentaria Morton											
sp. nov. (same as sp. nov. from Snow Hill, N. C.)											×
Crassatellites sp. (cast)				×							
Undetermined casts of pelecypods								×			
Belemnitella americana (Morton) ?											

ARTHROPODA.

The subkingdom Arthropoda is represented among the fossils from the well by specimens of Ostracoda. A species of Cytheridea, closely related to *C. perarcuata* Ulrich, was obtained from sample 25, depth 454 feet; a few Ostracoda were found in samples 26–48, depths 478 to 890 feet; and a few specimens of unidentified Ostracoda were also found in some of the samples taken between depths of 920 and 2,007 feet.

VERTEBRATA.

A few remains of fossil vertebrates were obtained from samples representing the Cretaceous portion of the section, as follows:

Samples 50, 54, 55, taken at depths of 920, 1,000, and 1,015–1,030 feet, respectively, *Corax falcatus* Agassiz (a shark); sample 70, 1,375–1,400 feet, Lamna?; samples 72, 83, 86, from depths of 1,440–1,450, 1,660–1,670, and 1,720–1,723 feet, respectively, shark teeth; sample 92, 1,800–1,812 feet, coprolite; sample 98, 1,839 feet, *Corax falcatus* Agassiz; sample 100, 1,841 feet, Ptychodus? (fragment of tooth).

PLANTS.

The only plant remains found in the samples were a few fragments of lignite in sample 1, depth 40 feet; numerous fragments of lignite from samples 109, 110, and 112, depth 1,974–2,007 feet; and numerous comminuted vegetable fragments in sample 111, depth 1,974–2,007 feet.

RECORD OF ANOTHER WELL AT CHARLESTON.

The record of a well 1,980 feet deep, drilled under the auspices of the city council of Charleston between the years 1876 and 1879 by Mr. F. Spangler, is inserted here for purposes of comparison. The well is known as the Citadel Green well and is at the southwest corner of the South Carolina Military Academy grounds, near the corner of King and Calhoun streets. A scientific committee was appointed by the city council to cooperate with the city civil engineer "in devising and employing the best means of preserving, recording, and classifying the stratifications of the new well and publishing a statement of the work when done."[1]

This committee sent a set of borings from the well to Prof. James Hall, whose report to the chairman of the committee is here quoted in full.[2]

New York State Museum of Natural History,
Albany, June 21, 1880.

Right Rev. P. N. Lynch, *Bishop of Charleston:*

I very much regret that it was not in my power to give prompt attention to the collection of specimens from the artesian well at Charleston which you placed in my hands, but you already know why I was not able to do so.

I herewith hand you some memoranda regarding the collection as it came into my hands and as indicated by marks showing the number of feet in depth. These depths are sometimes specifically marked, and in other cases the specimens in the box or parcel are marked as extending over many feet. Some of the specimens of fossils can be readily identified, but most of them are too fragmentary to give the means of satisfactory specific determination, and I have indicated only their generic relations.

The species described by Capt. Vogdes,[3] with a single exception, do not appear in the collection in a condition to be satisfactorily determined.

The higher beds are clearly of the modus Tertiary. There is nothing in the collection that indicates the presence of Cretaceous strata at any point above 600 feet. The parcel marked 600 to 1,300 feet contains Cretaceous forms, and the specimens marked respectively 654–767 and 700–720 feet have all the aspect of Cretaceous marl or green sand but are without fossils. At 900 feet there occur teeth of *Ptychodus mortoni* Leidy, a characteristic Cretaceous fossil.

[1] Artesian wells: The report of the scientific committee appointed by the city council on July 5, 1876, consisting of the Rev. P. N. Lynch, D. D., Prof. C. U. Shepard, jr., and J. F. M. Geddings, M. D., embracing a historical sketch of the several attempts, from 1823 to the present time, to bore artesian wells in this city; also an elaborate analytical investigation of the waters and the strata penetrated in the artesian wells and other analyses of cistern waters and of waters from many of the large fire wells of this city: Municipal report of the city of Charleston, S. C., 1881, 61 pp. Charleston, 1882.

[2] Idem, pp. 21–24.

[3] Am. Jour. Sci., 3d ser., vol. 16, pp. 69, 70, 1878.

The lowest depth of any marked specimens of fossils is 1,955 feet, and the parcel contains characteristic Cretaceous forms. The specimens indicated as 1,940–1,980 are of greenish clay, without fossils.

Regarding the Tertiary as terminating at the depth of about 600 feet this will give nearly 1,400 feet (1,980−600=1,380) of the Cretaceous formation in vertical thickness.

The lowest marked specimens of fossils are of characteristic Cretaceous forms and present no remarkable change from those several hundred feet higher in the series. From the character of these fossils we should be warranted in the inference that there may be a considerable thickness of Cretaceous beds below that horizon.

The clay indicated by the numbers 1,940–1,980 feet has the character of the lower clays of the Cretaceous formation in some localities, but it would be imprudent to draw any positive inference without further knowledge.

Truly yours,

James Hall,
State Geologist and Director State Museum Natural History.

Notes on samples of borings from different depths of the artesian well at Charleston, S. C.

Depths.
65–100. Pliocene, Tertiary, Tellina, Arca, etc.
80–100. Tertiary, Venus, Tellina, shark's tooth, phosphatic nodules.
350–430. Tertiary, phosphatic nodules, oyster-shell breccia. [600 feet noted by Capt. Vogdes as containing Chama. No specimens.]
680. Shell marl, concretions. Nothing indicating geological position.
600–1,300. Cretaceous, *Exogyra foliacea*, iron pyrites nodules, soft limestone of calcareous rock with phosphate. Specimens marked as above; no indication of specific depth.
654. Cretaceous, marl with fragments of shells.
767. Cretaceous, marl with green sand, Anomia? sp. (fragmentary).
778. Cretaceous, phosphatic concretions, green sand, iron pyrites.
700–720. Cretaceous, compact marl, oolitic and micaceous shells which are indeterminable.
900. Cretaceous, *Ptychodus mortoni* Leidy (a characteristic Cretaceous fossil).
1,090. Cretaceous, calcareous marl with fragments of shells.
1,345. Cretaceous, Ostrea sp.?, *Gryphæa vomer.*
1,345–1,350. Cretaceous, *Exogyra costata*, *Gryphæa vomer*, charred wood.
1,349. Cretaceous, marl with sand, green sand, siliceous concretions.
1,369. Cretaceous, marl with sand, *Exogyra foliacea.*
1,400–1,403. Cretaceous, concretions of sand in a greenish marl.
1,472. Cretaceous, concretions of sand in a greenish marl with shell breccia.
1,520. Cretaceous, argillaceous marl.
1,533–1,538. Cretaceous, sand with shells, casts of shells, and shells of Ostrea, Exogyra, Anomia? sp., *Neithea mortoni* D'Orb.
1,553. Cretaceous, breccia of shells and bryozoans, Ostrea, fragments of bones, Serpula, lignite.
1,570. Cretaceous, green sand, *Exogyra costata.*
1,575. Cretaceous, green sand, siliceous concretions, Ostrea.
1,580. Cretaceous, green sand, argillaceous.
1,588. Cretaceous, green sand and marl, without shells.
1,558–1,560. Cretaceous, sand, concretions, micaceous, *Exogyra foliacea*, Inoceramus (fibrous portion of shell), Exogyra, fragments, Ostrea, casts of indeterminable fossils in green sand.
1,558. Cretaceous, valve of *Exogyra foliacea.*
1,600. Cretaceous, Inoceramus (fibrous portion of shell), *Exogyra costata*, Dentalium.
1,600–1,610. Cretaceous, green sand with Exogyra, Teredo.
1,610–1,620. Cretaceous, green sand with Exogyra.
1,625–1,650. Cretaceous, green sand with Exogyra, Ostrea.
1,650–1,675. Cretaceous, green sand with Exogyra, *Gryphæa vomer*, *Exogyra costata.*
1,690. Cretaceous, green sand with Exogyra.
1,690–1,705. Cretaceous, green sand with casts of fossils and fragments of Exogyra.
1,692–1,700. Cretaceous, green sand and marl.
1,700–1,725. Cretaceous, green sand and marl, Ostrea, Gryphæa.
1,710. Cretaceous, green sand, siliceous.
1,728. Cretaceous, green sand, siliceous.
1,730–1,750. Cretaceous, green sand, Exogyra.
1,745. Cretaceous, green sand, siliceous.
1,765. Cretaceous, green sand, siliceous, fragments of Exogyra, Ostrea, upper valve of *Exogyra costata.*
1,790. Cretaceous, green sand.
1,831. Cretaceous, *Exogyra costata.*
1,835. Cretaceous, fragments of bones and Exogyra, two forms of Bryozoa, undetermined siliceous aggregations.

Depths.	
1,845.	Cretaceous, Exogyra, shell, breccia.
1,840.	Cretaceous, Exogyra, Ostrea, young of *Gryphæa convexa*.
1,840.	Cretaceous, echinoderm (Bucleolites?).
1,850.	Cretaceous, fragments of bone, siliceous pebble.
1,835–1,840.	Cretaceous, Exogyra, Gryphæa, sand, pyrite, Dentalium, bones, shark's teeth of the genera Ptychodus and Lamna, echinoderms, *Nucleoletes* (*Catophygus*) *lynchii* Vogdes.
1,844–1,845.	Cretaceous, shells of *Gryphæa vomer?*, *Exogyra costata*.
1,840–1,845.	Cretaceous, sandstone with fragments of shells, shell breccia, *Exogyra costata* (young), *Gryphæa pitcheri*.
1,845.	Sand pump, Cretaceous, *Gryphæa pitcheri*, *Gryphæa vomer*, sand concretions.
1,835–1,840.	Cretaceous, concretions of coarse sand, shells, Ostrea, *Gryphæa shephardi*, Exogyra.
1,840.	Cretaceous, shark's teeth.
1,840–1,940.	Cretaceous, fish bone, Inoceramus sp.?
1,900(?).	Cretaceous, sand, Ostrea.
1,900(?).	Cretaceous, shark's tooth, pebble, sand.
1,932.	Cretaceous, green sand, casts of fossils, pebbles, lignite, iron pyrite, Gryphæa.
1,930.	Cretaceous, clay.
1,930.	Cretaceous, micaceous sandstone.
1,900.	Cretaceous, sandstone, iron pyrite, green sand, fine laminated clay.
1,900.	Cretaceous, Inoceramus, wood.
1,900.	Cretaceous, exterior shell of Inoceramus.
1,900.	Cretaceous, Teredo.
1,923.	Cretaceous, green sand, casts of Gastropoda, Inoceramus, Ostrea.
1,940.	Cretaceous, phosphatic nodule with iron pyrite, sand aggregation with mica.
1,943.	Cretaceous, lignite, red hematite.
1,950.	Cretaceous, wood opal, iron pyrite.
1,949–1,980.	Cretaceous, clay.
1,955.	Cretaceous, lignite, iron pyrite.
1,955.	Cretaceous, shell breccia, Nucula, Turritella.
1,955.	Cretaceous, shell breccia, siliceous, Ostrea.
1,955.	Cretaceous, oyster perforated by sponge, green sand, iron pyrites, Inoceramus.

According to Prof. Hall's interpretation the Cretaceous was reached in this well at a depth of 600 feet, although no characteristic Cretaceous fossils are recorded from a definitely determined depth less than 900 feet. Prof. Hall's report contains two proposed specific names of fossils, namely, *Exogyra foliacea* and *Gryphæa shephardi*, which were not subsequently described and which are therefore invalid.

The present writer has not been able to learn what disposition was made of the fossils from this old well.

CORRELATION OF THE STRATA PENETRATED.

STRATA OF PLEISTOCENE AND PLIOCENE AGE.

The fossil mollusks in samples Nos. 1 to 4 were submitted to Dr. Paul Bartsch, of the United States National Museum, who regards those obtained from samples 1 to 3, representing depths from 40 to 75 feet, as of probable Pleistocene age and those from sample 4, depth 82–83 feet, as certainly of Pliocene age.

STRATA OF UPPERMOST EOCENE OR OLIGOCENE AGE.

Samples 5 to 8, representing depths from 86 to 220 feet, contain a rich foraminiferal fauna, the species of which have been identified by Joseph A. Cushman. The names of the species and their distribution in the well are given in the table on pages 79–80 and the fauna is discussed in the quotation that follows the table. The lithology of the samples shows that they belong to the Cooper marl, which outcrops in the vicinity of Charleston and which is referable to either the uppermost Eocene or the Oligocene. R. S. Bassler states that he has recognized ostracodes in the Cooper marl which appear to indicate that it is of Vicksburg age. On the other hand, the formation has yielded mollusks and the vertebrate genus Basilosaurus, which Vaughan and others have regarded as indicating its Jackson age.

STRATA OF EOCENE AGE.

A part of the samples numbered from 9 to 24, representing depths ranging from 262 to 447 feet, were obtained as concentrates from the overflow. These consist largely of fragments of limestone, fragments of shells, echinoid spines, and Bryozoa. Samples 9, 11, and 13, depths 262 to 350 feet, were derived from layers of rather soft limestone or marl, but they yielded no determinable fossils. Samples 17, 20, 22, 23, and 24, depths 363 to 447 feet, are made up chiefly of fragments of hard gray sandy limestone containing numerous indeterminable fragments of mollusks and a few fragments of echinoids and Bryozoa. These samples appear to be essentially alike lithologically and probably represent one geologic formation. From samples 22 to 24, depths 435 to 447 feet, R. S. Bassler has identified the species of Bryozoa listed on page 81. He reports that the fauna is closely related to the bryozoan fauna in the Castle Hayne limestone,[1] of Jackson (Eocene) age, exposed near Wilmington, N. C., and to a similar fauna in the Mount Hope marl of Sloan,[2] exposed near Eutawville (Eutaw Springs), 70 miles north of Charleston, S. C.

Vaughan,[3] because of the presence of *Ostrea sellæformis* Conrad, has correlated the Mount Hope marl of Sloan with the Claiborne group, but evidence afforded by the Bryozoa indicates that it may be of Jackson age.

Although the stratigraphic and age relations of the upper Eocene and Oligocene deposits of this area have not been definitely determined, the fact that normally the strata dip coastward and the evidence afforded by the fossil bryozoans seem to support the view that the limestones and marls penetrated in the Charleston well between depths of 262 and 447 feet represent the buried coastward extension of the Mount Hope marl of Sloan. However, the evidence cited on page 85, which appears to indicate the Jackson age of the Cooper marl, necessitates questioning the correlations here suggested.

Sample 25, depth 454 feet, contains ostracodes belonging to the genus Cytheridea and closely related to the species *C. perarcuata*, which occurs in the Eocene of Maryland in both the Aquia and Nanjemoy formations.

STRATA OF EOCENE OR UPPER CRETACEOUS AGE.

Samples 26 to 42, representing depths between 478 and 742 feet, yielded no fossils of sufficient diagnostic value to permit the determination of the age of the beds. A few specimens of Ostracoda and Foraminifera were obtained, but it was not certain that they belonged in place at the levels from which they were taken; indeed, it seemed highly probable that they fell from higher levels. Lithologically, the samples present no features of value for correlation. The upper part of the thickness represented (264 feet) is probably Eocene and the lower part Cretaceous, but without more exact data the point of contact can not be determined. The samples obtained as concentrates consist chiefly of gray shaly, finely arenaceous, micaceous, calcareous clay containing more or less loose sand. One sample (No. 29, depth 504 feet) is a highly glauconitic loose sand. The samples obtained as mud from the bit consist of gray calcareous, more or less sandy clays. The lithology of these samples indicates that they may belong to either the Eocene or Cretaceous. The basal beds of the Eocene that outcrop in the Coastal Plain of South Carolina along the borders of the Cretaceous areas north and northwest of Charleston consist in part of dark shaly clays, the buried extension of which some of these samples might well represent. The glauconitic sand (sample 29, depth 504 feet) may perhaps represent the glauconite-bearing Warley Hill marl of Sloan (part of Claiborne group). Many of the samples below the glauconitic layer are not essentially different from those above it.

STRATA OF UPPER CRETACEOUS AGE.

The first definite paleontologic evidence of strata of Cretaceous age was afforded by species of Foraminifera found in sample 43, depth 750 feet. Dr. Cushman has discussed this evidence in the quotation given on page 81. From this depth to a depth of 920 feet the samples indicate

[1] Miller, B. L., The Coastal Plain of North Carolina; the Tertiary formations: North Carolina Geol. and Econ. Survey, vol. 3, pp. 185–197, 1912.
[2] Sloan, Earle, Catalogue of the mineral localities of South Carolina: South Carolina Geol. Survey Bull. 2, ser. 4, p. 462, 1908.
[3] Vaughan, T. W., in Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 737, 1912.

that the drill encountered sands and clays, more or less calcareous and glauconitic, containing small black phosphatic pebbles. Some hard layers were penetrated, as is shown by fragments of sandstone in the samples.

The first identifiable mollusk of undoubted Cretaceous age, *Anomia argentaria* Morton, was found in sample 50, taken at a depth of 920 feet. The strata penetrated from 920 feet to the bottom of the well, as represented by the samples, are typical marine Upper Cretaceous materials, consisting of marls, more or less calcareous and glauconitic, sands, and shaly clays, with indurated layers at intervals. These samples yielded the identifiable fossils listed on preceding pages.

The writer has heretofore attempted [1] to explain the lithologic variations and age relations of the Cretaceous deposits of the eastern Gulf region and to correlate them with the Cretaceous deposits of the North Atlantic region. Figure 11, which indicates the terms employed in that report to designate the paleontologic zones recognized and the relations of these zones to formation units, is introduced in order that the Charleston well section may be compared with the Chattahoochee and Carolina sections. In figure 12 the correlation of the Cretaceous portion of the Charleston well sections, in terms of the faunal zones recognized in these regions, is indicated diagrammatically.

The following fossils were identified specifically in samples taken between depths of 920 and 1,550 feet:

Mollusca: *Ostrea larva* Lamarck, *Ostrea plumosa* Morton, *Pecten venustus* Morton, *Lima reticulata* Forbes ?, and *Belemnitella americana* (Morton) ?.

Vertebrata: *Corax falcatus* Agassiz (a shark).

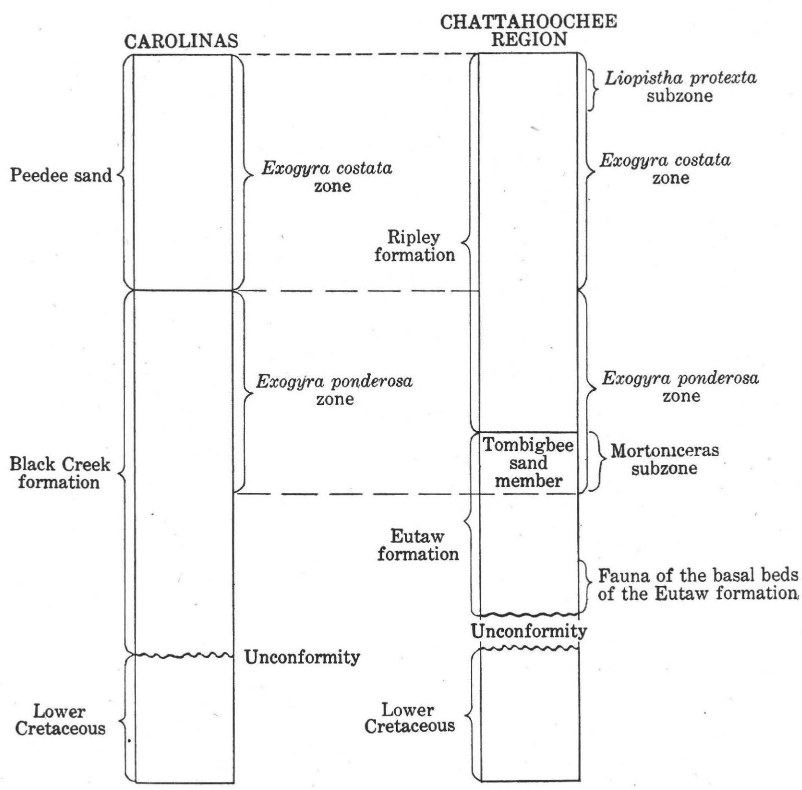

FIGURE 11.—Diagram indicating the terms used to designate paleontologic zones and the relation of these zones to formation units in the Chattahoochee region and the Carolinas. Horizontal dashed lines indicate age equivalencies within the Upper Cretaceous. Not drawn to scale, and relative thicknesses of formations not indicated accurately. The Ripley formation of the Chattahoochee region is approximately the time equivalent of the Selma chalk of western Alabama and east-central Mississippi and of the combined Ripley formation, Selma chalk, and upper part of the Eutaw formation of northern Mississippi.

Of the fossils listed, *Ostrea plumosa* Morton and *Lima reticulata* Forbes range through both the zone of *Exogyra costata* and the zone of *Exogyra ponderosa*, and *Ostrea plumosa* Morton has been questionably identified from the basal beds of the Eutaw formation; *Ostrea larva* Lamarck ranges from the zone of *Exogyra costata* downward into the upper part of the zone of *Exogyra ponderosa*. *Corax falcatus* Agassiz is a wide-ranging species in the Upper Cretaceous. In known sections *Pecten venustus* Morton and *Belemnitella americana* (Morton) are restricted to the zone of *Exogyra costata*, and upon the evidence of these fossils this portion of the section is correlated with that zone. Heretofore the species *Pecten venustus* Morton has not been found below the horizon of *Belemnitella americana* (Morton). As it was found here 300 feet below the level at which the fragment of Belemnitella was obtained, it is considered probable that it fell to that position from some higher level. In terms of the formation units recog-

[1] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region and species of Exogyra from the eastern Gulf region and the Carolinas: U. S. Geol. Survey Prof. Paper 81, 1914.

nized in the Upper Cretaceous deposits of the Carolinas this portion of the section (depth 920–1,550 feet) is correlated with the Peedee sand.

Between the depths of 1,725 and 1,862 feet the following fossils were identified specifically:

Vermes: *Hamulus onyx* Morton.

Mollusca: *Ostrea cretacea* Morton, *Exogyra ponderosa* Roemer?, and *Pecten quinquecostatus* (Sowerby).

Vertebrata: *Corax falcatus* Agassiz (a shark).

Of these fossils, *Hamulus onyx* Morton and *Pecten quinquecostatus* (Sowerby) range throughout both the zone of *Exogyra ponderosa* and the zone of *Exogyra costata* but are not found in the basal beds of the Eutaw formation; *Ostrea cretacea* Morton ranges from the basal beds of the Eutaw formation upward into the lower half of the zone of *Exogyra ponderosa; Corax falcatus* Agassiz has a wide vertical range in the Upper Cretaceous; and *Exogyra ponderosa* Roemer is restricted to the zone that bears its name. On the evidence afforded by the range of these fossils this part of the section is correlated with the zone of *Exogyra ponderosa* of the Chattahoochee and Carolina regions.

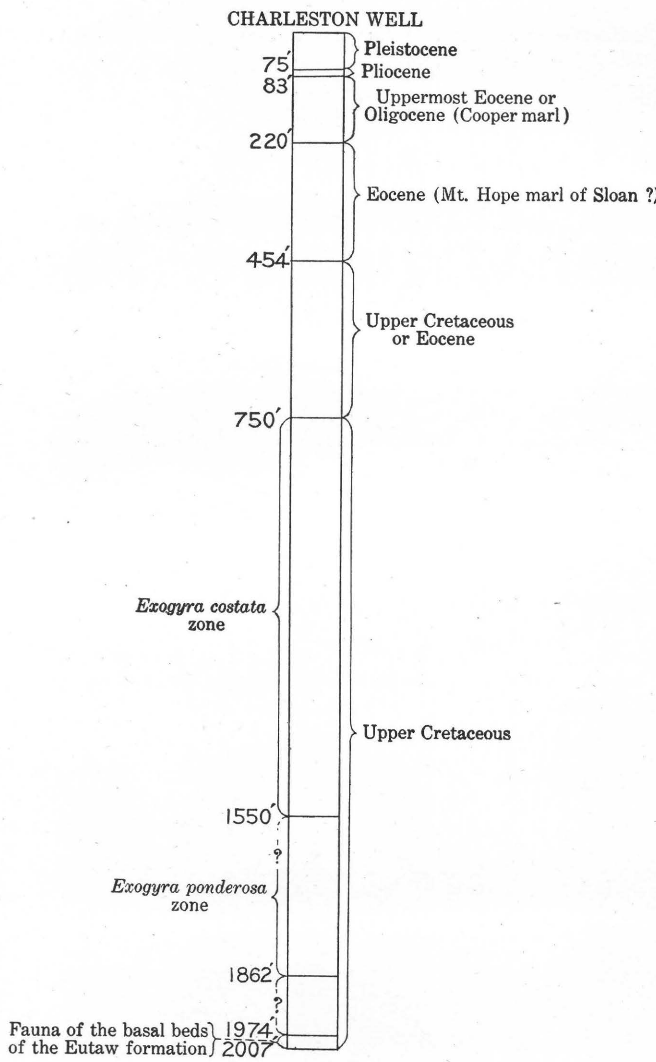

FIGURE 12.—Diagram showing correlation of Cretaceous portion of the Charleston well section in terms of the faunal zones recognized in the Cretaceous deposits of the eastern Gulf region. All measurements were made from the top of the rotary jaws, which was 6 feet above the surface of the ground.

The best specimens obtained from the Cretaceous strata penetrated by the boring were those brought to the surface by the natural flow of water from depths between 1,974 and 2,007 feet. The fossils identified specifically from this horizon are the following:

Mollusca: Ostrea sp. nov. *a* (four fairly good specimens and other fragments), Ostrea sp. nov. *b*, *Ostrea cretacea* Morton, *Exogyra upatoiensis* Stephenson[1] (three fairly good specimens and several fragments), Anomia sp. nov. (same as sp. nov. from Snow Hill, N. C.).

Of the species listed, Ostrea sp. nov. *a* and *b* are new to science, and their value in correlation has not been determined. *Ostrea cretacea* Morton ranges upward into the lower half of the zone of *Exogyra ponderosa; Exogyra upatoiensis* Stephenson has been found heretofore only in the basal beds of the Eutaw formation in the Chattahoochee region; Anomia sp. nov. (same as a new species from Snow Hill, N. C.) ranges upward into the zone of *Exogyra ponderosa.* The particular localities at which *Exogyra upatoiensis* Stephenson have been found are the following: Broken Arrow Bend, Chattahoochee River $10\frac{1}{2}$ miles below Columbus, Ga.; Chattahoochee River, one-half mile below Broken Arrow Bend; and a bluff on Upatoi Creek 7 miles southeast of Columbus, Ga., below the Cusseta road bridge.

On the evidence of *Exogyra upatoiensis* Stephenson this horizon is correlated with the basal beds of the Eutaw formation in the Chattahoochee region. Exposures of these beds occur in

[1] This species was described by the writer in U. S. Geol. Survey Prof. Paper 81, p. 46, pl. 13, figs. 1–4, 1914.

bluffs on Upatoi Creek, which forms the boundary between Muscogee and Chattahoochee counties, Ga., and on Chattahoochee River from a place a short distance below the mouth of Upatoi Creek, 9 miles below Columbus, Ga., nearly to the mouth of Euchee Creek, about 16 miles below Columbus.

In terms of the formation units recognized in the Carolinas, that portion of the section between a depth of 1,550 feet and the bottom of the well represents a part—perhaps the greater part—of the Black Creek formation.

ORIGIN AND GEOLOGIC HISTORY OF THE WATER.

The strata underlying the Atlantic Coastal Plain in the Carolinas consist of a series of sands, clays, and marls, largely unconsolidated, and subordinately of impure limestones. These rest unconformably upon a basement complex of ancient crystalline rocks of pre-Cambrian age and locally upon Triassic sedimentary strata which occupy depressions in the crystalline rocks. These older rocks outcrop in the Piedmont Plateau, along the eastern border of which their upper eroded surface dips slightly southeastward and passes beneath the deposits of the Coastal Plain, becoming deeper toward the coast.

At Fort Caswell, N. C., which is on the coast at the mouth of Cape Fear River, the crystalline basement rocks lie about 1,535 feet below sea level, as is shown by a well boring. At Charleston they lie more than 2,000 feet below sea level, for the deep wells there have failed to reach the basement.

The formations above the basement rocks in South Carolina in the longitude of Charleston embrace deposits comprising in ascending order Lower Cretaceous, Upper Cretaceous, Eocene, Oligocene (?), Pliocene, and Pleistocene. The strata composing the formations dip coastward at the rate of 40 feet or less to the mile. The younger formations in general lie flatter than the older, the youngest, the Pleistocene terrace deposits, having an inclination of less than 5 feet to the mile.

The materials composing the sands, clays, and marls of the formations of the Coastal Plain were derived primarily from the predominantly feldspathic rocks of the Piedmont Plateau, with the exception of the matter, chiefly calcium carbonate, that was extracted by organisms or chemically precipitated from the sea water in which the deposits were for the most part laid down. The more easily soluble minerals of the crystalline rocks of the Piedmont were in part leached out and carried to the sea in solution by the streams, but some of the feldspathic matter was transported coastward as detrital material in different stages of decay and became incorporated in varying proportions in the formations of the Coastal Plain. The capacity of the different strata of the Coastal Plain for admitting water and their efficiency as channels for circulation differ greatly. Some of the beds are compact and almost impervious to water; some are porous and where the structural conditions are favorable permit the free circulation of water.

The underground waters in the deposits of the Coastal Plain have been derived from several sources, including water entering from the adjacent Piedmont Plateau, rainfall on the Coastal Plain, and originally included sea water.

The greater part of the run-off from the Piedmont Plateau flows to the ocean in streams which, though they cross the Coastal Plain, probably do not contribute materially to the underground supply. The mass of underground water in the deeply weathered surficial rocks of the Piedmont, however, tends by gravity to drift coastward, some of it doubtless passing into the deposits of the Coastal Plain. Of the land-derived underground water rainfall on the Coastal Plain itself is doubtless the chief original source of supply. Water from either source comes into contact with feldspathic minerals, either in the rocks of the Piedmont Plateau itself or in the formations of the Coastal Plain which were derived from the crystalline rocks of the Piedmont Plateau, and from these minerals have been derived the characters which distinguish the underground waters of the area.

The more deeply buried beds also contain water composed of a mixture of originally included sea water and subsequently included alkaline land water, both of which may properly be classed as fossil waters. The character of the fossil waters in the vicinity of Charleston is discussed by Chase Palmer on pages 90–94 of this paper.

The strata penetrated in the Charleston wells are all of marine origin, and probably the greater part of the Cretaceous deposits and the lower part of the Eocene deposits have never been above sea level since their formation, so that no opportunity has been afforded for draining these ancient waters from them. During subsequent geologic time land-derived waters have moved downward along the gently dipping strata and have become mixed with the originally included sea waters in varying proportions in the different beds and at different places. The composition of the waters has been further changed by the solution of mineral matter from the deposits in which the waters have stood and by the precipitation of mineral matter from solution.

The conditions and principles governing the origin, storage, and circulation of underground waters in North Carolina, which are equally applicable in South Carolina, have been discussed by Stephenson and Johnson.[1]

RÉSUMÉ.

1. The first 75 feet of strata penetrated in the Charleston well is probably of Pleistocene age.
2. Characteristic Pliocene fossils were found in a sample taken at a depth of 82–83 feet.
3. Sands and clays bearing Foraminifera, which have been studied by Joseph A. Cushman, were penetrated at depths of 86 to 220 feet. On the grounds of lithologic similarity these samples are referred to the Cooper marl.
4. Strata of Eocene age (the Mount Hope marl (?) of Sloan) were penetrated from depths of 262 to 454 feet.
5. The strata between depths of 454 and 750 feet yielded no determinable fossils. Their age is Upper Cretaceous or Eocene.
6. From a depth of 750 feet to the bottom of the well only strata of Upper Cretaceous age were encountered.
7. At a depth of 750 feet Foraminifera were found which are regarded by Dr. Cushman as characteristic Cretaceous species.
8. Between depths of 920 and 1,550 feet fossils characteristic of the zone of *Exogyra costata* of the eastern Gulf region and the Carolinas were obtained.
9. Between depths of 1,725 and 1,862 feet fossils characteristic of the zone of *Exogyra ponderosa* of the eastern Gulf region and the Carolinas were obtained.
10. Between depths of 1,974 and 2,007 feet fossils characteristic of the fauna of the basal beds of the Eutaw formation in the Chattahoochee region were brought to the surface by the natural flow of water immediately after the well was completed.
11. In view of the fact that at the lower limits of this boring, which reached a depth of nearly 2,000 feet below sea level, no Lower Cretaceous beds had been reached, it is interesting to note that at Wilmington, N. C., and at the mouth of Cape Fear River, N. C., borings which reached basement crystalline rocks at 1,100 feet and approximately 1,535 feet, respectively, below sea level, failed to encounter strata older than Upper Cretaceous.

MINERALOGY OF WATERS FROM ARTESIAN WELLS AT CHARLESTON, S. C.

By Chase Palmer.

PRIMARY ALKALINE FOSSIL WATERS.

The writer made a complete analysis of the water from the new well at the power plant of the Charleston Consolidated Railway & Lighting Co. at the foot of Charlotte Street and a parallel analysis of the water from the old artesian well at the corner of Meeting and Wentworth streets, Charleston, with two objects in view—first, to compare the quality of the water of the old well (1,260 feet deep) with that of the new well (2,007 feet deep), and, second, to determine what changes, if any, might have taken place in the quality of the water of the old well since 1868, the date of its first recorded analysis. It may be stated here that no material change is shown either in the chemical character of the solution or in its concentration 44 years after it was analyzed by Charles U. Shepard, who, in 1882, published many analyses of waters of wells

[1] Stephenson, L. W., and Johnson, B. L., Water resources of the Coastal Plain of North Carolina: North Carolina Geol. and Econ. Survey vol. 3, pt. 2, pp. 342–348, 1912.

in and near Charleston.[1] The mineralogy of these artesian waters is here briefly outlined and is compared with that of one other well water underneath Charleston and with that of the water of surface streams of the Piedmont Plateau.

On Citadel Green, in Charleston, in 1876, a well was sunk to a depth of 1,980 feet, and a fairly complete analysis of the water coming from that depth was then made by S. T. Robinson, jr. The Citadel Green well evidently reached the same underground water that supplies the new 2,007-foot well of the Consolidated Railway & Lighting Co., for the waters of the two wells exhibit a close resemblance in mineralization. This resemblance is not confined to the degree of concentration of mineral substances but extends to the chemical qualities of the two solutions, for the reaction properties of the water of the 2,007-foot well are proportionally the same as those of the water of the 1,980-foot well, which was analyzed 35 years ago.

The waters at the 1,260-foot level and at the 1,980-foot level under Charleston differ markedly in the proportions of their reaction properties. This fact, taken in connection with the fact that the character of each solution remains practically unchanged after an interval of several decades, leads directly to the conclusion that these two artesian waters are from independent watercourses. On the other hand, they have in common certain peculiarities which might be expected if the natural conditions governing their original sources and their present environment were recognized.

By reason of its higher position and the impervious underlying granite the Piedmont Plateau is naturally one source of the water contained in the sands that are buried under material derived from the upland. It is therefore desirable to know, first, the quality of surface waters now flowing in the Piedmont area and of the surficial waters of the upper Coastal Plain before they enter the ground water of the Coastal Plain, and, second, the quality of the underground waters near the coast, as indicated by the waters of three artesian wells under the city of Charleston, S. C. In order to show the character of the surface waters the waters of Peedee and Wateree rivers are chosen, because they typify the river waters of the Piedmont Plateau and upper Coastal Plain of the southern Atlantic coast. The qualities of the series of surface waters from the James in Virginia to the Ocmulgee in Georgia are tabulated in a recent publication of the United States Geological Survey.[2]

The analysis of an artesian water coming from a depth of 425 feet, to be used in a comparative study of the waters from the two lower levels, is obtained from the records of the municipal report of Charleston on artesian wells, already cited.

INTERPRETATION OF ANALYSES.

As the interpretation of water analyses adopted in this report is new, its novelty warrants a preliminary statement of the principle on which it is based and justifies definitions of the terms used in its application. This chemical interpretation is based, not on the amounts of the constituents found by the analyst, but on their reaction capacities, and thus is opened a way leading directly to a consistent nomenclature of water qualities and a consistent classification of waters, as has been shown by the writer elsewhere.[3]

In recent years the geologist has relied on the statement of the results of a water analysis for information concerning the quality of the water analyzed. A mere statement of the amounts of radicles, which are only parts of substances dissolved in a water, has no chemical significance, for it tells nothing of the qualities of the solution, the characterization of which is the chief object of the analysis.

Fortunately the chemist is able to measure quantitatively four qualities of the water solution without resort to a complete analysis. The qualities capable of direct measurement are acidity, permanent hardness, temporary hardness (temporary alkalinity), and permanent alkalinity. A fifth quality of water, namely, saltness, caused by strong acid salts of the alkalies, can not be so easily determined. This quality may be found, however, by balancing the reacting

[1] Municipal report of the city of Charleston, S. C., for 1881.
[2] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, Table 2, opp. p. 16, 1911.
[3] Palmer, Chase, op. cit.

values of the positive and negative radicles found by analysis after deducting the reacting values of all the radicles that go to make up the other qualities directly measurable in the water solution. By proportionating this quality with the other qualities found in a water a rational statement of the chemical character of the water solution may be obtained.

FORMULA OF THE SOLUTION.

The reaction capacities of the radicles of the salts dissolved in water are the quotients obtained by dividing the weight of each radicle by its corresponding equivalent combining weight. The quotients thus obtained have been called the "reacting values" [1] of the radicles.

Owing to the differences in the concentration of waters the application of the reacting values to the character of water is necessarily restricted to the water under examination. If, however, the reacting values are expressed in percentages of their sum they may be used in the comparative study of different waters. This expression of the reacting values of the radicles in percentages is called the formula for the mixture of salts dissolved in a water, and on this formula rests the comparative study of waters in this report.

PROPERTIES OF NATURAL WATERS.

Nearly all natural waters have two general properties—salinity and alkalinity—on whose relative proportions their fundamental characters depend. All the radicles of the alkalies and alkaline earths tend to form alkaline solutions, but only the strong acid radicles (sulphate, chloride, nitrate) can overcome this tendency and render an alkaline solution neutral or saline. The sum of the reacting values of the strong acid radicles is therefore a measure of the salinity (saltness) of a natural water which is a solution of salts of strong and weak acids. The sum of the reacting values of the metallic radicles in excess of the values of the strong acids is a measure of the alkalinity of a water.

In the qualities of waters included in this report only two kinds of salinity and two kinds of alkalinity will be considered. In accordance with the prevalence of the reacting values of the alkali group (sodium, potassium) and the alkaline earths group (calcium, magnesium) four special properties are possible, namely:

1. Primary salinity (alkali salinity)—that is, saltness such as would be caused by sulphates and chlorides of the alkalies.
2. Secondary salinity (permanent hardness)—that is, saltness such as would be caused by sulphates and chlorides of calcium and magnesium.
3. Primary alkalinity (permanent alkalinity)—that is, alkalinity such as would be caused by hydroxides, carbonates, and bicarbonates of the alkalies.
4. Secondary alkalinity (temporary hardness)—that is, alkalinity such as would be caused by weak acid salts of calcium and magnesium.

Secondary salinity and primary alkalinity are incompatible, so that both of these qualities are not found in the same water. The waters considered in this report are represented by three qualities; for instance, an assemblage of 1, 3, 4, or an assemblage of 1, 2, 4, exemplified by ocean water.

COMPARISON OF WATERS.

The analyses of the waters of Peedee and Wateree rivers (columns 1 and 2 in the accompanying table, p. 93) show that they are very dilute solutions having practically the same concentration. Moreover, these two waters are almost identical in composition, as may be seen by comparing the amounts of the radicles in column 1 with the amounts of the radicles in column 2. This close similarity in composition of two surface waters in different river basins at points 70 miles apart cross-country is noteworthy and is in marked contrast with the evident difference in composition of the three underground waters (columns 3, 4, 5) at Charleston, at levels separated by vertical distances of only a few hundred feet.

[1] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, p. 356, 1908; also, chapter on industrial application of water analyses in U. S. Geol. Survey Water-Supply Paper 274, pp. 161-181, 1911.

TABLE 1.—*Analyses and formulas of surface and artesian waters and of ocean water.*

[Analyses in parts per million; formulas in percentages of reacting values.]

Constituent.	River waters of Piedmont Plateau.				Artesian waters at Charleston, S. C.						Ocean water (formula).
	Analyses.		Formulas.		Analyses.			Formulas.			
	1	2	1a	2a	3	4	5	3a	4a	5a	6
Sodium (Na)	7.4	7.2	19.3	19.1	1,154	1,014	421	43.6	47.4	49.1	38.5
Potassium (K)	1.8	1.6	2.8	2.5	146	41	4.4	3.3	1.1	.3	.8
Calcium (Ca)	6.1	5.7	18	17.2	21	14	3	.8	.8	.4	1.8
Magnesium (Mg)	1.9	2.3	8.7	11	31	8.3	.4	2.3	.7	.1	8.9
Iron (aluminum) (Fe) (Al)	.6	.1	1.2	.1	....	Tr.	1.0	....	....	.1	....
Sulphate (SO_4)	4	4.2	5.2	5.5	271	Tr.	7.2	4.8	0	.5	4.6
Chloride (Cl)	2.1	2.2	3.8	4	1,483	944	92	36.4	27.1	6.7	45.2
Bromide (Br)	....	....	....	....	....	Tr.	Tr.	....	Tr.	Tr.	.1
Nitrate (NO_3)	.7	.4	.6	.4	....	....	....	....	....	....	....
Bicarbonate (HCO_3)	40	39	40.4	40.1	(a)	1,115	872	(a)	19.8	38.1	....
Carbonate (CO_3)	0	0	0	0	303	41	54	8.8	3.1	4.7	.1
Silica (SiO_2)	28	27	....	....	40	36	32	....	....	....	....
Total solids	72.2	69.8	100	100	3,449	2,655	1,051	100	100	100	100

a Condition in solution unknown. CO_3 estimated in residue.

1. Peedee River at Peedee, N. C. Average of 10 analyses made at U. S. Geological Survey in 1908.
2. Wateree River at Camden, S. C. Average of 15 analyses made at U. S. Geological Survey in 1908.
3. Artesian well at Chisholm's mill, Charleston, S. C. Depth, 425 feet. Analyzed in 1879 by William Robertson.
4. Old artesian well at corner Meeting and Wentworth streets, Charleston, S. C.; 1,260 feet deep. Analyzed in 1912 by Chase Palmer.
5. New artesian well at Charleston Consolidated Railway & Lighting Co.'s station, Charleston, S. C.; 2,007 feet deep. Sunk in 1911. Analyzed in 1912 by Chase Palmer.
6. Ocean water. Values obtained from average results of 77 analyses of sea water given in *Challenger* report. The average concentration of sea water is 35,000 parts per million.

TABLE 2.—*Reaction properties of Piedmont surface waters, of waters of artesian wells, and of ocean water.*

	1	2	3	4	5	6
Primary salinity	19	20	82	57	14	78.6
Secondary salinity	0	0	0	0	0	21.1
Primary alkalinity	25	23	12	40	85	0
Secondary alkalinity	56	57	6	3	1	.3
	100	100	100	100	100	100.0

Aside from such observations as these there is little to be gained by considering the amounts of the constituents found in a water, but in the formulas derived from the reacting values of the constituents the relative reaction capacities of all the constituents can be seen at a glance. For instance, the relative reaction capacity of the alkalies and alkaline earths in surface waters flowing in areas of crystalline rocks is illustrated in column 1a. The sum of the reacting values of the alkalies (Na, K) is 22.1 and the sum of the reacting values of the alkaline earths (Ca, Mg) is 26.7. Thus the aggregate values of the alkaline earths exceed the aggregate values of the alkalies by 4.6 per cent, although the alkaline earths weigh less than the alkalies (column 1). Again, the combined weights of the sulphates and chlorides (column 1) is exactly equal to the weight of calcium (6.1), yet their capacity of neutralizing calcium is notably deficient because the sum of the reacting values of chlorides and sulphates (column 1a) is 9 and the reacting value of calcium is 18.

In general, calcium and magnesium are potent factors of quality in surface streams, and their importance in this respect is due largely to their relatively high reaction capacities, which must be considered if the full chemical value of these two constituents is to be appreciated. Unfortunately, writers on the geochemistry of waters have fixed their attention on the absolute weights of the dissolved constituents, so that they have failed to observe important facts concerning the chemical character of waters, especially facts relating to geology. Too much stress can not be laid on the consideration of the reaction capacity of every constituent that contributes to the quality or character of the water solution, for it is by their measurable qualities that solutions as well as other homogeneous substances are characterized. It is surprising that, in their attempts to characterize and classify waters, hydrologists have failed to apply this basic principle of chemical science.

The summaries of reaction properties of the three artesian waters (Table 2) show remarkable regularity in the variations in the proportions of all their properties. They are all primary alkaline solutions and hence are referable to a common origin, namely, the Piedmont Plateau, whose surface streams are uniformly characterized by primary alkalinity. Again, the progressive decline in the proportion of salinity (from 82 per cent to 14 per cent) among the properties of these waters in connection with constantly increased dilution of the solutions suggests at once that at increasing distances from the surface these waters are less and less affected by still stronger saline solutions found in the Coastal Plain.

The formulas of these three artesian waters (Table 1) present a picture showing in detail the differences in the relative values of all the constituents. The preponderance of sodium in these underground waters as compared with its value in the Piedmont Plateau surface waters is noteworthy. The low values of calcium and magnesium are no less striking than the changes that appear in their relative prominence. In the water of the 425-foot well magnesium exceeds calcium. This relation is not known to exist in any of the surface waters of the Piedmont Plateau from Virginia to Georgia or in the Coastal Plain river waters entering the eastern Gulf of Mexico. In all these river waters calcium exceeds magnesium by a wide margin.[1]

The excess of magnesium over calcium in the water of the 425-foot well, taken in connection with the high proportional values of chlorides and sulphates, points directly to the presence of ocean water (column 6), in which the relations of all these constituents are similar. Although magnesium does not prevail over calcium in the waters at the two lower levels, nevertheless in the waters of the 1,260-foot and 2,007-foot wells traces of bromides have been found. Additional evidence is thus presented that water of marine origin has been retained in minimal amounts even by these deep-seated landward waters. The beds in which these waters occur were deposited in sea water, and doubtless sea water was entrapped in the rocks. In consideration of the restricted circulation underground it does not seem unreasonable to conclude that even at 1,260-foot and 2,007-foot levels mixtures of fossil primary alkaline waters with fossil sea water—that is, water of the secondary saline type—may be found.

The water of the 2,007-foot well as it emerges at the surface contains a slimy precipitate the composition of which is shown in the following analysis:

Analysis of slime from water of a well 2,007 feet deep at Charleston, S. C.

[Analysis reported Sept. 3, 1912.]

SiO_2	55.79
Al_2O_3	23.80
Fe_2O_3	4.50
FeO	1.41
CaO	2.43
MgO	1.87
K_2O	2.45
Na_2O	1.18
MnO	.02
H_2O	6.50
	99.95

Slimes of this kind are said to be present in the waters of newly drilled deep wells in this vicinity. After the waters have flowed for longer or shorter periods they gradually clarify.

The consideration of fossil waters has hitherto been restricted to solutions of the secondary saline type. A brine obtained from a well more than 5,000 feet deep in West Virginia has recently been examined by the writer. This is evidently a fossil water, a relic of a Devonian sea. Its secondary salinity represents 45 per cent of its properties, a proportion of secondary salinity more than twice as high as that of modern sea water.

It is just as reasonable to suppose that waters of the primary alkaline type are capable of fossilization as it is to suppose that secondary saline waters are fossil.

[1] U. S. Geol. Survey Bull. 479, Tables 2 and 3, 1911.